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Framing solar energy
an analysis of solar photovoltaics in British agriculture

Ledingham, B.

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Farming Solar Energy:

An Analysis of Solar Photovoltaics in British Agriculture

B. Ledingham

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Abstract

The introduction of the Feed-in Tariffs by the UK Government in 2010 provided a financial subsidy for renewable energy arrays and substantially reduced the return on investment period. Subsequently, the agricultural industry has been at the forefront of the onshore renewable market, providing both locations for arrays and consumers for the electricity produced. However, little research has been done into this recent trend, and the motivations, problems and impacts associated with it have gone largely unexplored. In light of greenhouse gas emission reduction targets for the agricultural industry, solar photovoltaic (PV) arrays could provide a cost positive mechanism for mitigation.

This study used complementary methods of both quantitative and qualitative data collection, gathered using a postal survey of farmers who have PV arrays. The presence of two main drivers for PV array installation by farmers is shown: environmental and financial, although these are not necessarily mutually exclusive. It is also suggested that low farmer education levels and access to finance for tenant farmers might be preventing further uptake within the industry.

Evidence on the impacts that PV arrays are having on British farms is also presented. These include high returns on investment, which provide significant additional income for many farmers, allowing them to invest back into their businesses. Ground-mounted solar PV arrays can also benefit the local farm environment by reducing the amount of land farmed intensively and, if managed correctly, can provide habitats for wildlife and improve biodiversity. This research also shows that the assumption that renewable energy arrays increase energy efficiency amongst adopters is inaccurate, and they do not encourage wider reductions in farm carbon footprints. These findings have implications for the design of renewable energy policy, particularly as policies are changing rapidly in response to the unexpected high uptake of solar PV arrays.

Author's Declaration

I declare that the dissertation embodies the results of my own research or advanced studies and that it has been composed by myself. Where appropriate, I have made due acknowledgement to the work of others.

Content removed on data protection grounds

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List of Abbreviations

AES	Agri-Environment Schemes
AHA	Agricultural Holdings Act
CAP	Common Agricultural Policy
CCC	Committee on Climate Change
CCRA	Climate Change Risk Assessment
CFT	Cool Farm Tool
CH_4	Methane
CLA	Countryside and Land Association
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DCLG	Department for Communities and Local Government
DECC	Department for Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DNO	District Network Operator
EPA	Environmental Protection Agency
EPIA	European Photovoltaic Industry Association
EPSRC	Engineering and Physical Sciences Research Council
EREC	European Renewable Energy Council
FAO	Food and Agriculture Organisation
FBT	Farm Business Tenancy
GAEC	Good Agricultural and Environmental Condition

GB	Great Britain
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHGAP	Greenhouse Gas Action Plan
GO	Science Government Office for Science
Gt	Gigatonnes
GVA	Gross Value Added
GW	Gigawatts
Ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
KS	Kolmogorov-Smirnov
kWh	kilowatt hours
LEAF	Linking Environment and Farming
Mt	Megatonnes
MWh	Mega Watt hours
N_2O	Nitrous Oxide
NFRU	National Farm Research Unit
NGOs	Non-Governmental Organisations
ONS	Office for National Statistics
POST	Parliamentary Office of Science and Technology
PV	Photovoltaic(s)
ROI	Return On Investment
RSPB	Royal Society for the Protection of Birds

SPS	Single Payment Scheme
TSO	The Stationary Office
UK	United Kingdom
UN	United Nations
US	United States
WGS	Woodland Grants Scheme

Chapter 1. Introduction

1.1 Introduction

Solar photovoltaic (PV) panels are a technology that convert energy from solar radiation into direct current electricity, using semiconductors that exhibit the photovoltaic effect. They are therefore one of the technologies that provide renewable energy. The first solar cell was operational in 1954, but it was not until the new millennium that global commercial use was established in the form of solar PV arrays (Mendonça, 2009). A rapid global increase in PV deployment has occurred since then.

The main rationale for increasing the use of renewable energy is that of anthropogenic climate change. The scientific consensus states that the release of large amounts of GHGs, mostly from the burning of fossil fuels, is causing irreversible climatic change (Cook *et al.,* 2013). Climate policy has been developing since 1988, when the Intergovernmental Panel on Climate Change (IPCC) was created (Kandlikar *et al.,* 2005). Since then a variety of national and international policies have attempted to limit GHG emissions, and the EU in particular has been at the forefront of this effort. Renewable energy arrays reduce GHG emissions, as once they are built they produce almost no emissions, unlike conventional fossil fuels.

Climate change is a national issue as well as an international one. Under a medium GHG emission scenario, central England temperatures are predicted to increase by 2°C – 6.4°C by 2080, with further implications for rainfall patterns (Defra, 2009). This will have an impact on the economy as well - the Stern report (2006) predicted that climate change could have an annual negative impact of 5% of global GDP. The agricultural industry will arguably suffer the most, with changes to the growing season, flooding, heat stress in livestock, storm damage and increased risks from pests and diseases being just some of the possible negative effects (Defra, 2009).

The UK was the first state in the world to enshrine in law the reduction of GHG emissions on a large scale (Climate Change Act, 2008), and has set a target of national GHG emission reductions of at least 34% of 1990 levels by 2022 (CCC, 2008). As part of its European commitments the UK is also committed to sourcing 15% of its energy from renewable sources by 2020 (European Parliament, 2009), equivalent to 31% of its electricity (Farming Futures, 2010b). In response to this a series of 'carbon budgets' were set out detailing how this goal is to be achieved. The agricultural industry has been set the target of reducing their emissions by 11% by 2020 (Greenhouse Gas Action Plan, 2012). Agriculture is responsible for 9% of GHG emissions in the UK (CCC, 2013). Estimates suggest that the emissions reduction potential of renewable energy within the industry could outweigh this target by a factor of six (Greenhouse Gas Action Plan, 2012).

Due to inherent land ownership, the agricultural industry has been at the forefront of onshore renewable energy generation in Britain. However, unlike other major renewable technologies such as wind turbines and anaerobic digestion, PV is suitable for a wide range of farms and estates. The main limiting factor for suitability is that the aspect of the roof or land needs to be between south west - south east in order to maximise the amount of solar irradiation received (Solar PV, 2013). PV panels are at their highest generation capacity during the day and in the summer. Farms and estates that have dairies, crop drying facilities or offices for example, have their peak energy usage at these times and therefore are particularly well placed to take advantage of PV (Dairy Development Centre, 2012).

In Britain, PV deployment has increased exponentially since the government introduced the Feed-in Tariff (FiT) subsidies in April 2010. The FiTs effectively reduced the return period for investment and stimulated uptake (Farming Futures, 2010b). PV was included as a key technology in the government's Renewables Roadmap for the first time in 2012 (DECC, 2012a). DECC published the first part of a full Solar Strategy in 2013 (DECC, 2013b) and the full roadmap in April 2014 (DECC, 2014a).

Despite climate change and renewable energy being extremely important issues for both society and agriculture, very little academic research has been done exploring the uptake of renewables by farmers/landowners, and none has been done specifically on PV. The grey literature has begun to explore these relationships, but large-scale and rigorous work has yet to be undertaken. The research presented in this thesis is an initial analysis of the role PV arrays are having in British agriculture. It will examine a broad range of issues in order to establish areas of interest and possible future work. The importance of environmental verses financial reasons for installing an array are important to understand in order to use policy to influence uptake. Identifying the barriers to uptake follows on from this, and can help to focus policy in areas where perhaps farmers and land managers differ in their needs from other sections of society. At the same time it is also important to assess what the impacts of PV have been for farmers/landowners who already have it, in order to learn from them and assess whether what is perceived to be a beneficial technology is having the desired effect.

This research makes a unique contribution to academic and policy literature in two ways. Quantitative data collection will provide some key statistics to give an overview of the way in which PV is being used in agriculture. Qualitative analysis will explore the impact of agricultural PV arrays, and through consideration of behaviours and attitudes will suggest further policy improvements to increase the uptake of PV in agriculture.

1.2 Aims and Objectives

The aim of this research is to explore the role PV is performing in British agriculture. To fulfil this aim, the following objectives will be met:

1. To examine the characteristics of farmers/landowners who have installed PV arrays, and to identify the motivations behind this decision.
2. To explore the impacts of PV on a farm scale.

3. To examine the barriers to further PV implementation in the agricultural sector.
4. To identify any changes in attitude and behaviour to reducing GHGs by farmers/landowners with PV arrays.

This will be achieved by undertaking a large-scale survey of farmers/landowners who already have PV arrays installed, in order to analyse their experiences. The survey will have a broad range of questions in order to gather complementary data. It is beyond the scope of this thesis to look at farmers who have expressed interest in PV, but have not gone through with installation, as these farmers/landowners would be extremely difficult to identify. In order to gain an overall understanding of the experiences involved, the depth of the research will be limited to identification of issues rather than a full exploration of them.

1.3 Thesis Structure

The following chapter will introduce the climate change debate, and will explore both international and national climate policy. It will focus on the impacts climate change may have on agriculture, as well as the discussion in the literature on mitigation in this sector. Chapter 3 discusses PV policy in the UK, including a brief history of government subsidies and exploration of the recent controversy regarding the FiT scheme. It then goes on to discuss the topic of farmer decision-making, before outlining the existing literature on farmers/landowners and PV.

In the fourth chapter an explanation of the research methods used will be presented, including the sampling strategy and data analysis techniques employed. Chapter 5 presents the data analysis from the questionnaire sent out to farmers/landowners who already have PV arrays, whilst Chapter 6 presents an analysis of the qualitative data taken from the survey.

A discussion of the themes brought up by the quantitative and qualitative data is given in Chapter 7, including the impact of these on the existing literature and for PV policy. Chapter 8 concludes the study by highlighting the limitations of the research and outlines recommendations for further study and suggested policy changes.

Chapter 2. Climate Change and Agriculture: A Review of the Literature

This research draws upon many principles from different areas of academic discipline, and therefore needs to be put in context by examining the wide range of literature on its central thematic areas. The scientific theory of climate change is central to this research, therefore this chapter will begin by summarising the key literature on climate change. It will then go on to focus specifically on agriculture and climate change: its greenhouse gas contributions, the impacts of climate change on agriculture and the potential for mitigation in this sector.

2.1 Climate Change

The phrase climate change can be defined as ‘any significant change in the measures of climate lasting for an extended period of time’ (EPA, 2013). The discussion of climate change can be traced back to 1824, when the French physicist Joseph Fourier first described the earth’s greenhouse effect (Fleming, 1999).

2.1.1 Observed Change

Historical patterns of climate change cannot be measured directly, and so proxy records must be used to help infer and recreate past climates. Proxy records such as ice cores (Thompson *et al.,* 2000), tree rings (Koch, 2009) and properties of sediments (Mangeruda *et al.,* 2003) have been used in such a way. Modern temperatures and climatic change can be directly measured using monitoring instruments. For 160 years this has been done on the ground, as well as via satellites during the past forty years. Using these methods, it has been shown that the earth has warmed by approximately 0.7°C over the past century (Knox *et al.,* 2012). This warming pattern has not been uniform though, with significant warming occurring in the early parts of the twentieth century, slight cooling in the middle (Jones and Moberg, 2003) and greater warming in the latter part of the century (IPCC, 2007). Since the mid- 1970s, global average temperatures increased at an average of 0.17°C per decade (IPCC, 2007). However global temperature signals can be complicated by a host of natural events. Temporary cooling can be induced by injection of sulphur into the atmosphere, as occurred after the 1991 Pinatubo volcanic eruption (Briffa *et al.,* 1998), and coupled ocean-atmosphere forcing from El Niño and El Niña can increase and decrease global temperatures respectively (IPCC, 2007). The superposition of both natural and anthropogenic forcing signals, along with the inherent internal variability of the climate system, means that attributing causality to climatic change can be a difficult task (Ammann and Wahl, 2007).

2.1.2 The Anthropogenic Theory and Alternatives

The anthropogenic theory of climate change dictates that the increased release of GHGs from human activities, which has increased exponentially since the industrial revolution, is preventing long-wave radiation from escaping the earth's atmospheric system and is thus increasing global temperatures and causing climatic change. These GHGs include methane (CH_4), water vapour and nitrous oxide (N_20), however CO_2 is the currently the biggest contributor, responsible for 63% of gaseous radiative forcing (Hofmann *et al.,* 2006). Proxy records show that temperatures have been increasing throughout the Holocene (the term used for the current geological epoch- circa 11,700 year ago until present), but recent decadal temperature increase is greater than previous maxima, and the last decade is highly likely to be the warmest in the last millennium (Li *et al.,* 2007). This theory has been accepted by the influential IPCC (2007) report with 'very high confidence', as well as a large body of researchers such as Hegerl *et al.* (2007) and Stott *et al.* (2006). Despite the widespread media coverage of the IPCC (2007) report, alternative theories of climate change continue to have significant coverage in the media and in general society. In response to this Cook *et al.* (2013) conducted a meta-analysis of the peer-reviewed climate change literature in order to illustrate that the scientific consensus is almost universal. They examined 12,000 abstracts spanning two decades. Of those expressing an opinion on anthropogenic climate change, 97.1% accepted the theory. They also illustrated that the proportion of research rejecting anthropogenic causes is decreasing over time.

As well as the theory that contemporary climate change is simply a part of the natural climatic system (Hulme *et al.,* 1999), alternative theories of climate change have been proposed. These relate to external influences, such as cosmic rays. For example Rao (2011) hypothesized that as cosmic rays act as cloud nuclei, a decrease in primary cosmic rays results in lesser low cloud cover, which in turn reduces the albedo (the fraction of shortwave radiation reflected from the Earth back into space) of the earth and less incoming short wave radiation is reflected back into space. This increases the surface temperature of the earth. Ice core records show that the primary cosmic ray intensity has decreased by 9% during the last 150 years. This mechanism provides a possible explanation for solar driven climate change different from changes in solar irradiance, such as Svensmark (2007) has proposed.

2.1.3 Climate Science

Although the anthropogenic theory of climate change has been almost universally accepted amongst scientists, climate change science itself has inherent challenges associated with data collection and analysis which add to the complexity and uncertainty of understanding processes and making predictions. A good example of the difficulty of statistics is the now infamous ‘hockey stick graph’ (a graph of historic temperatures showing a sharp rise over the past few centuries) of Mann *et al.* (1998) which has been both refined (Mann and Jones, 2003) but also subsequently critiqued (McIntyre and McKitrick, 2005; Ammann and Wahl, 2007).

Even the IPCC reports, the most comprehensive scientific documents ever published, contain many uncertainties. In their 2001 and 2007 reports, the

IPCC presented future projections of climate change parameters based on different socio-economic projections of GHG emission scenarios. The uncertainty not only lies with the extent of future emissions, but also with how these translate into global temperature increases and subsequent changes to climatic patterns. Estimates are constantly being revised as the science becomes better understood. Smith *et al.* (2009) outlines the reasoning behind a lower estimation of the temperature increase needed before 'dangerous anthropogenic interference' occurs as decided upon in the IPCC (2007) report. This includes strengthened observations of impacts already occurring, a greater understanding of the likelihood and magnitude of climatic events, more precise identification of heavily affected geographical regions and growing evidence that even modest increases in temperature could cause positive feedbacks and cause large impacts over multi-century timescales. In terms of climate processes, cloud feedback mechanisms remain perhaps the largest source of uncertainty (Edwards, 2008).

The rate at which predictions can be proven wrong is highlighted by Rahmstorf *et al.* (2007), who compiled the most recent climate data and compared it to the projections that the IPCC made in their 2001 report. They found that most of the projections have already been surpassed by the current climate. The global mean surface temperature increase was 0.33°C for 1990-2006, which is in the upper part of the range projected by the IPCC. Rates of sea level rise in particular have responded to forcing much quicker than anticipated. Satellite data show a linear trend of 3.3 ± 0.4 mm/year sea level rise whereas the IPCC projected a rise of less than 2 mm/year.

Another complexity of the climate system that will become more apparent is significant time lags between cause and effect. It is thought that past emissions are expected to contribute an estimated further 0.2°C increase per decade in global temperatures for the next two to three decades, irrespective of any mitigation efforts during that time period (IPCC, 2007). A global surface temperature change of up to 6.4°C is likely using a high emissions scenario (IPCC, 2007), one which has already being surpassed since 2000

(Raupach *et al.*, 2007). Improving climate models to incorporate all these variables is the main focus for improving climate science and therefore making predictions more accurate (IPCC, 2007).

2.1.4 Climate Policy and Targets

Perhaps the inaugural event of international climate policy was the creation of the IPCC in 1988, set up to collate and analyse scientific data and information on climate change and to use this to inform recommendations for policy (Kandlikar *et al.,* 2005). International and national policy is needed to limit GHG emissions, and thus the degree of climatic warming. In 1992 Article 2 of the United Nations Framework Convention on Climate Change committed signatory nations to stabilizing GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNCCC, 1992). Next came the legally binding Kyoto Protocol which was signed in 1997 and ratified in 2005, which laid the foundations for international carbon emissions and renewable energy targets (Edwards, 2008). The target for total global emission reductions was 20-24 billion tonnes of CO_2e by 2050, with a further 8-10 billion tonnes CO_2e by 2100. This was aimed at limiting the temperature rise by 2100 to close to 2°C (CCC, 2008). The EU is committed to a reduction in CO_2 emissions to 92% of baseline (1990) levels during the first commitment period, 2008-2012. The Kyoto Protocol also recognises emissions offsetting, for example from the better management of agricultural soils. However the Kyoto Protocol has been heavily critiqued as inadequate (Cooper, 2001) and it has been plagued with disputes, with Canada withdrawing in December 2011 citing economic costs of meeting targets as their rationale (The Guardian, 2011). Country capacity and ineffective enforcements have been identified as key problems by Edwards (2008).

There have been a host of summits at which climate change policy has been debated, such as Rio+20 in 2012, with a view to progressing from the Kyoto Protocol. However conflict over the divide of responsibility between developed and developing countries has prevented many agreements (Raupach *et al.*, 2007). Together, the developing and least-developed economies, forming 80% of the world's population, accounted for 73% of global emissions growth in 2004 but only 41% of global emissions and only 23% of global cumulative emissions since the mid-18th century (Raupach *et al.*, 2007). Rio+20 also illustrated that the short term concerns of countries, such as the global economic downturn, is often given more importance than long-term issues such as climate change. Overall, Bradshaw and Borchers (2000) point out that even the guidance produced by the IPCC, unprecedented in its scale and complexity, has failed to lead to decisive international policy. There is a large gap between climate change science and policy (Shackley and Wynne, 1996).

The EU was an early driver of international cooperation efforts (Lövbrand, 2011), with a climate change programme that began in 2000 (Prag, 2012). Climate science and policy were closely linked, but since the financial crisis the EU has revaluated its stance on climate change and is more wary of the potential upfront economic costs of action (Haug and Berkhout, 2010). National policy is also needed to sit alongside international policy if significant and long-lasting reductions in GHG emissions are to be made. One viewpoint championed by Giddens (2009) is that for this change to happen, decarbonisation across all sectors in a country is essential. To achieve this, action is needed at a level that is above party politics and spans across different governments. This must include both mitigation strategies and adaptation strategies (Patt and Dessai, 2005).

2.1.5 UK Context

The UK has seen an average temperature increase of 1°C since the mid-1970s (Jenkins *et al.*, 2009). Under a medium GHG emission scenario, central England temperatures are predicted to increase by 2°C – 6.4°C, summer precipitation reduce by 17% - 23% and winter precipitation to increase by 14% - 23% by 2080 (Defra, 2009). These predictions were made by the UKCP09 models: peer reviewed projections of future climate change scenarios funded by the UK government and designed by a consortium of stakeholders. The UK has a strong record of climate change governance compared to many other countries, as it has both national and EU level emissions targets. The UK government commissioned the Stern Review (Stern, 2006) to explore the economic implications of climate change for the UK. This review used economic models to predict that the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP per year. This figure rises to 20% if a wider range of risks and impacts is taken into account. However the costs of mitigation could be limited to around 1% of global GDP each year (Stern, 2006). Although convincing in its conclusions, the economic models used by the review have been severely criticised by Nordhaus (2007), Dasgupta (2007) and Weitzman (2007).

Subsequently, the Climate Change Act (2008) enshrined in law the reduction of GHG emissions on a large scale, with the UK being the first state in the world to do so (Knox *et al.,* 2012). The UK's Committee on Climate Change stated that national GHG emissions should be reduced by at least 34% of 1990 levels by 2022 (or 42% if an international agreement on climate change is reached) and 80% of 1990 levels by 2050 (CCC, 2008). A series of five year carbon budgets were set out fifteen years in advance to help achieve this goal, with subsequent implications for UK energy policy (see DECC, 2011). A UK wide Climate Change Risk Assessment (CCRA) is also carried out every five years and a National Adaptation Programme for each UK country must be done after the CCRA. However it has been argued that the targets set by the Climate Change Act and the inherent top-down approach it uses are problematic (Anderson *et al.*, 2008). Despite there being much more still to be done, the UK is setting itself up to be a global leader in mitigation and adaptation.

2.2 Agriculture and Climate Change

Climate change has the potential to have a huge impact on agriculture around the world, as it exacerbates the issues of weather prediction and extreme events that already pose large challenges for the agricultural sector (Defra, 2012c).

2.2.1 Agricultural GHG Contribution

Agriculture is estimated to contribute 10–12% of GHG emissions globally, including those associated with fertiliser production (Smith *et al.,* 2007). This figure rises to 17-32% or more when costs beyond the farm gate, especially land conversion, are included (Bellarby *et al.*, 2008). Moreover, agriculture contributes a disproportionate amount of GHGs that have a high impact on warming, approximately 47% and 58% of total CH_4 and N_20 emissions respectively. N_20 has 298 times the global warming potential of CO_2 (IPCC, 2006) and CH_4 has 25 times the potential (Farming Futures, 2010c). Of the total emissions from agriculture, CO_2 makes up 10%, N_20 50% and CH_4 the remaining 40% (Farming Futures, 2010c). Without additional policies, agricultural N_2O and CH_4 emissions are projected to increase by 35–60% and ~60%, respectively, by 2030 (IPCC, 2007).

The single most important contribution of agriculture to GHG emissions is through the production and application of nitrogen fertilizers (GOScience, 2011). N_20 release is a consequence of natural biological nitrogen fixation, therefore it cannot be entirely eliminated from the system (Smith and Conen, 2004). The second most significant is the CH_4 released from livestock production through enteric fermentation and manure (Oenema *et al.,* 2005). CO_2 in agriculture is released by burning fossil fuels, in the production of agricultural chemicals and directly in machinery on farms. Therefore the variability in GHG emissions between the different agricultural sectors is significant (CCC, 2013). Hence GHG emissions from agriculture also vary geographically, with N_20 being the main contributor to emissions in the West, Africa and most of Asia, whilst CH_4 emissions from livestock dominate from Central and South America, Eastern Europe, Central Asia and the Pacific region (GOScience, 2011).

In the UK, agriculture is responsible for 9% of GHG emissions (CCC, 2013). Emissions in this sector are already down by 30% from 1990 levels partly due to a decrease in livestock numbers, but also due to more efficient fertiliser production and use (DECC, 2011). (Discussion of the error involved in these figures can be found in 2.2.3). The CCC (2009) report asked the agricultural sector in England to reduce emissions by 3 million tonnes of CO_2e, which is roughly an 11% decrease, by 2020 (Farming Futures, 2010c), and the DECC (2011) report outlined how this might be achieved. Other parts of the UK are setting their own targets as policy becomes increasingly devolved, further encouraging small-scale energy generation.

2.2.2 Impacts on Agriculture in the UK

73.9% of land in the UK is used for agricultural purposes (Home, 2009). Agriculture in the UK can be roughly divided into two different types due to climate, soils and topography. Pastoral farming is found in areas of higher rainfall and relief, predominantly to the north and west of the UK. Arable farming is concentrated in the south and east of the UK where the climate is drier and soils are deeper. However the nature of pastoral and arable farming can vary greatly, so a further division of farm types can be made. The Farm Business Survey (2011/2012) uses the following distinctions: cereals, dairy, general cropping, horticulture, upland grazing livestock, lowland grazing livestock, mixed, pigs and poultry. There are large differences between the scale, labour use, control of environments, inputs and outputs of these farming types.

There is an extremely wide range of both peer reviewed and grey literature focussing on the potential future impacts of climate change on agriculture. The first element of uncertainty and potential error in these predictions stems from the emissions scenarios and general circulation models used. The second arises from the crop models used. Therefore these predictions have large margins of error associated with them (Aggarwal and Mall, 2002). Most existing research has focussed on the effect of climate change on the yields of current major crops.

In addition to greater global mean temperature rises, models suggest that climate change will also increase the frequency and severity of extreme events (IPCC, 2007). This may already be evident in past events such as the European heatwave of 2003 (Beniston and Diaz, 2004). Several billion euros of crop damage was inflicted as temperatures rose and remained high, and European river levels reached an all time low. Other risks to agriculture stem from changes to the growing season, floods, increased heat stress in livestock, storm damage and increased risks from pests and diseases (Defra, 2009). However not all impacts will be negative, as some areas will become unsuitable for agriculture and others will become more viable. With higher temperatures and greater CO_2 concentrations some crops may increase in yield, and there may be opportunities to grow new crops (Defra, 2009). However models detailing the response of crops to changes in atmospheric composition have produced conflicting evidence, with the benefits of CO_2 fertilisation being less than previously thought (Long *et al.,* 2006) and potentially being counteracted by the damaging effects of increases in surface ozone (Long *et al.,* 2005). The spatial variability of the impacts of climate change on agriculture can be illustrated by looking at projected flooding changes in England and Wales. Currently around 50,000ha are at risk of flooding frequently, and this is projected to increase to around 200,000ha by 2080 (Defra, 2012c). However some agricultural land is also at risk from less frequent flooding and this is projected to increase from around 200,000ha at present to over 500,000ha by the 2080s (Defra, 2012c).

Semenov (2009) conducted a piece of research that illustrated the complexity of modelling climate change impacts on crops. He showed that the yield impact of drought stress on wheat in England and Wales was predicted to be smaller than that at present, because wheat would mature earlier in a warmer climate and thus avoid severe summer drought. Heat stress around flowering time may however be a greater problem and dramatically decrease yield. He also points out that complex non-linear interactions between a plant and its environment can make modelling extremely difficult. This shows that over-arching statements about cause and effect show a simplified picture (Witcombe *et al.*, 2008). In fact, some studies have predicted mean wheat yield increases in England and Wales of 11.5% (Semenov, 2009; Thomas *et al.,* 2011). Similar work has been done on potato crops in England by Daccache *et al.* (2011) with a 'potential' yield increase of 13-16%, however actual yields might only increase by 3-6% if limitations in water and nitrogen availability are not corrected. Trade-offs will also occur when it comes to pests and diseases. Wheat take-all may become more of a problem but wheat bulb fly will decrease in occurrence (Thomas *et al.*, 2011). The Knox*, et al.* (2012) report provides a holistic overview of climate change risk for agriculture in the UK, including discussion of the scope for new crops to be grown in certain regions.

Criticism of this kind of theoretical research includes Knox *et al.* (2012), who point out that there are many other more immediate threats to agriculture, such as energy prices, on which we should focus our efforts. Lobell and Burke (2008) have critiqued the strategic direction of research into climate change impacts on agriculture. They claim that uncertainties in estimates of impact are due to ignorance of the processes involved and that they are unhelpful for use in adaptation. They also criticise the lack of objectively prioritising research efforts, stating that in their view temperature change is more important as a focus for modelling than precipitation patterns, a point agreed on by Challinor *et al.* (2005). This is in contrast to Parry *et al.* (2004), who state that climate model downscaling to improve regional hydrological projections should be a research priority, especially as the models disagree on precipitation response to climate changes (IPCC, 2007). Schlenker and Roberts (2006) emphasize the importance of extreme events, highlighted also by Challinor *et al.* (2005) who suggest that there are thresholds above which crops become highly vulnerable to climate and weather. On a global scale, a changing and more variable climate will affect harvests of established cash crops which lead to food shortages and therefore global price increases (Defra, 2012c). Although this is not a linear relationship, as it can be distorted by market and trade policies (Parry *et al.*, 2004).

2.2.3 Mitigation

There are two modes of response to the threat of anthropogenic climate change, mitigation and adaptation. Mitigation involves reducing the input of GHGs into the atmosphere and/or removing GHGs directly from the atmosphere and storing them, in order to limit the severity of climate change. Adaptation involves altering processes and ways of behaviour in order to accommodate climatic changes. Although the agricultural sector has the potential to be severely affected by climate change, adaptation is not the focus of this study.

One of the key ways of reducing on-farm N_20 emissions is by using artificial fertilisers more efficiently (Farming Futures, 2010a). Techniques such as GPS technology can be used in precision farming to deliver different volumes of fertiliser to different parts of the field as required. Even taking account of weather conditions and application rate and style can reduce emissions (Bouwman *et al.*, 2002). Alternatively, leguminous crops can be used to boost nitrogen levels in the soil. Covering slurry and manure stores can also help by reducing rainfall mixing and oxidation (Farming Futures, 2010a). Off-farm, there are some more hi-tech approaches, such as increasing the efficiency of fertiliser production, and creating better nitrogen utilisation in crops, that can also reduce emissions (Farming Futures, 2010c).

Again, CH_4 emissions cannot be totally eliminated from agriculture. Manure stores, rice grown under flooded conditions and ruminant livestock are the main contributors to CH_4 emissions (Mosier *et al.*, 1998). Emissions can be reduced per unit of production through improved livestock health, modification of animal diets and breeding (Farming Futures, 2010c). For example an increase in concentrates and maize silage fed to cows can reduce CH_4, however this could also increase CO_2 emissions and so the overall net GHG effect has to be taken into account.

CO_2 emissions on the farm come from energy usage, microbial decay, burning of plant litter and soil organic matter, the disturbance of soils and changes in land use and land management (Farming Futures, 2010a). However quantifying these emissions can be extremely difficult (Plassmann *et al.*, 2010). Cultivated soils emit more CO_2 than natural soils because improved soil aeration and moisture contents lead to the increased decomposition of soil organic matter (Lal *et al.*, 2004). The return of plant materials such as dead leaves is also reduced. Therefore maintaining areas of vegetation cover, and using minimum or no-till systems can help reduce emissions. A host of energy efficiency measures will also reduce emissions on some farms.

Often mitigation decisions will affect the balance of more than one GHG so the overall affect must be considered, as well as whether the effect is temporary or permanent (Colomb *et al.*, 2012). The impact of the mitigation methods upon vulnerability and adaptability must also be taken into account. Win-win scenarios are possible, for example increasing soil organic matter can improve both fertility and reduce the impact of drought, improving adaptive capacity whilst also sequestering carbon (IPCC, 2007). Technological developments have been shown to be a key driver in achieving mitigation (Smith *et al.*, 2005a) as well as communication and capacity building.

Estimates of mitigation potential have large margins of error, due to uncertainties in the technical capacity of different mitigation techniques and technologies, as well uncertainties in the scale of their deployment. Therefore any estimates have to be treated lightly. Smith *et al.* (2008) estimated the mitigation potential for agriculture globally is 5500–6000 Mt of CO_2e per year through various management practices (for more information see Paustian *et al.*, 2004; Smith *et al.*, 2007). The UNFAO have estimated that agriculture could mitigate 80-88% of its CO_2 emissions (Reynolds and Nierenberg, 2012). A study by Freibauer *et al.* (2004) found that agricultural soils in the EU can sequester 16–19 Mt of carbon a year during the first Kyoto commitment period, which is less than one fifth of the theoretical potential. However they point out that any management change that carries the risk of increasing N_2O emissions could impact on farm profitability and that uncertainties in European scale estimates are greater than 50%. The CCC (2013) report suggested scope to reduce UK agricultural emissions by 10 Mt CO_2e by 2020 through cost-saving measures related to soils and livestock. It is important to note however that it is impossible to mitigate all emissions in agriculture as there will always be some from natural processes in the soil and in ruminant systems. So far there is little evidence that climate policy in Europe is affecting GHG emissions from agriculture (Smith *et al.*, 2005a). Some countries have agricultural policies designed to reduce GHG emissions, such as Belgium, but most do not (Smith *et al.*, 2005b).

In the UK, analysis undertaken has identified the potential to double emissions reduction to 10 Mt CO_2e in the 2020s through cost saving measures in agriculture. The policy focus is on cost-negative mechanisms, such as greater efficiency through farmer awareness and through incentives in the EU's Common Agricultural Policy (CAP) scheme, rather than cost positive ones such as a fertiliser tax. This is because of concerns that cost increases will decrease international competitiveness in the industry (CCC, 2013). Persuading farmers to change their behaviours is also of concern, as it has been widely shown in the literature that attitude does not directly relate to behaviour, therefore attitude change and behaviour change pose separate challenges. The next chapter will explore further the concept of farmer decision-making in the context of renewables and PV installations, after outlining the current PV policy in the UK.

2.3 Conclusion

The underlying rationale of this research - the anthropogenic theory of climate change - has been outlined alongside its inherent uncertainty. This stems from different future emissions scenarios as well as complex responses from the intricate climatic system. Policy responses to climate change struggle to deal with these complexities and the global scale involved. The EU and in particular the UK have led the way on target-setting and political commitment for both mitigation and adaptation strategies. These include ambitious targets for renewable energy deployment.

Agriculture is a significant contributor of GHGs but will also be heavily affected by climate change. Some of these effects are negative whilst others present opportunities for alternative farming systems. There is substantial potential for the mitigation of GHGs in agriculture, although quantifying this is difficult due to the heterogeneity of physical processes, and all predictions have a large margin of error associated with them. Cost positive mitigation measures are particularly prevalent and beneficial in agriculture, and this is where the policy focus lies. The next chapter will focus in more detail on one such cost positive measure, renewable energy, outlining PV technology and policy.

Chapter 3. Renewable Energy and PV in Agriculture

In this chapter the renewable energy sector in the UK will be briefly outlined, before a more detailed account of current PV activity in the UK and its mitigation potential is given. It will then go on to discuss the concept of farmer decision-making and how this may apply to the interaction between farmers/landowners and renewables. A review of current research on farmers/landowners and renewables is presented, examining the drivers of renewable uptake, barriers to uptake and potential impacts of arrays in turn. A summary of how PV arrays reduce carbon emissions is then given. Finally, the key gaps in the literature and previous research will then be highlighted, informing the conceptual model underpinning this thesis.

3.1 Introduction

The UK power sector, dominated by coal and gas-fired electricity plants, currently produces 27% of the UK's emissions (DECC, 2011). As part of its European commitments, the UK is committed to source 15% of its energy from renewable sources by 2020 (European Parliament, 2009), equivalent to about 31% of its electricity (Farming Futures, 2010b), and to draw up a National Renewable Energy Action Plan. In 2013 14.9% of UK electricity was generated by renewables (DECC, 2014c). However to meet national and international climate change targets total power sector emissions need to be close to zero by 2050 (DECC, 2011). New technologies can provide a low-carbon energy mix in order to meet these targets, but the majority need subsidies in order to compete with the heavily subsidised conventional energy industry (Prag, 2012).

One of the rationales behind the introduction of subsidies for renewables was that small-scale energy generation would encourage energy efficiency in consumers (Ofgem, 2009). However the opposite effect has also been postulated to be true, with consumers using more energy because they feel that they are already contributing to GHG reductions (West *et al.,* 2010).

Energy policy in the UK is not only designed to have an impact on reducing GHG emissions, but also has implications for energy security and economic growth. Energy security is about diversifying the technologies and types of energy used, including reducing imports of foreign oil and gas. It is thought that by 2020 the UK could be importing nearly 50% of its oil and 55% or more of its gas (DECC, 2011). Energy diversification will help to reduce the impact of price spikes, make the sector more resilient and may also have broader geopolitical repercussions. Increasing investment in the renewable energy industry also has a positive impact on growth, particularly job creation with estimates that thirty jobs are created for every MW of PV installed (POSTNOTE, 2012).

One such renewable technology is solar PV. The photovoltaic effect was first discovered in 1839 by Edmund Becquerel, but it was not until 1954 that the first PV cells were engineered (Perlin, nd). Their suitability led them to become widespread in satellite design. In the late 1950s the USA’s first satellite, Vanguard, was powered by PV. For the next few decades the space industry was the main consumer of PV. In the early 1970s a major breakthrough came when, due to new design and manufacturing methods, the cost of PV technology dropped from $100 per watt to $20 per watt (Perlin, nd). In 1977 total PV manufacturing production exceeded 500kW for the first time, and in 1979 a 3.5kW system in Arizona became the world's first village PV system. The price of PV panels has been decreasing since 1975, due to a combination of technical advances, and changes in finance due to knowledge, scope and scale effects in the industry (Perlin, nd). For example installed costs of PV arrays in the UK fell approximately 50% between 2010 and 2012 (DECC, 2013b). Large scale manufacturing in China has also led to a sharp decrease in prices in Europe, which means cheaper prices for the consumer, but some negative effects for the European domestic market as a whole. This issue of panel ‘dumping’ has led to a serious dispute between the EU and China, with the former threatening to levy heavy import tariffs on Chinese panels (DECC, 2013b). In July 2013 a minimum price for imported

Chinese solar panels was agreed after lengthy discussions (Solar Daily, 2013).

At the end of 2012 there was 102GW of installed PV capacity globally, estimated to be saving 53 million tonnes of CO_2 (EPIA, 2013) (see section 3.7 for further discussion on PV and carbon savings). It is now the third largest renewable energy source in terms of globally installed capacity (DECC, 2012a). Europe has the largest cumulative global capacity of PV, with more than 70GW. The next closest region is China, which has just 8.3GW (EPIA, 2013). PV now supplies 2.6% of the electricity demand in Europe (EPIA, 2013). Within Europe, Germany has the most developed PV industry. The first national programme was launched in 1990, the '100,000 Solar Roofs' programme, whereby loans were provided for private roof-based arrays. In 1998 there were just 30,000 people working in the renewables sector, a decade later that number was 300,000. Installed PV capacity is nearly 20GW (DECC, 2012a) and it supplies 5.6% of Germany's electricity (EPIA, 2013). Other countries have also had success in the PV market, grid parity has already been reached in India and Italy (World Business Academy, 2013). Grid parity refers to the point in time at which the costs of generating one unit of PV electricity are equivalent to, or become cheaper than, the retail price of one unit of electricity. Although predictions are difficult due to uncertainties over future policy development, electricity prices and module cost reductions, grid parity is predicted to be reached in the UK by 2020 (POSTNOTE, 2012).

3.1.1 PV Policy in the UK

The amount of solar irradiation the UK receives ranges from 960 kWh/m^2 in the far north, to 1240 kWh/m^2 in the south-west (POSTNOTE, 2012), therefore PV installations are more prevalent in the south and west of Britain (Figure 3-1). As of December 2013, the UK has 2.7GW of PV installed, made up of over 500,000 solar projects (DECC, 2014a). The UK solar market is ranked fourth highest in the world for growth and the highest in Europe for the large-scale solar market (Solar Power Portal, 2013). There is currently no data available on the installed PV capacity on agricultural land in the UK. However it is thought that renewable energy in agriculture will make a significant contribution to the government's 15% target (Greenhouse Gas Action Plan, 2012).

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Figure 3-1: Domestic solar PV installations per 10,000 households in September 2012 (DECC, 2012a).

Traditional fossil fuels have received subsidies for decades, and this market fails to internalize all costs and benefits of energy production and use. In order to compete, renewable energy technologies also need some form of subsidy (Sawin, 2004). These can be in the form of pricing laws, quota requirements, production incentives, tax credits or trading systems (Lipp, 2007). It is envisaged that eventually subsidies for renewables will no longer be needed as a combination of rising electricity prices and the decreasing cost of PV will allow grid parity to be reached (Post Solar PV, 2012).

It was not until 2002 that government policies were introduced to foster PV growth in the UK. In March 2002 the Major PV Demonstration Programme (MDP) was launched, providing grants for the overall cost of PV equipment and installation. This came to an end in February 2006. The Renewables Obligation (RO) was also introduced in April 2002 and still runs today. This scheme provides large-scale renewable energy generators (greater than 5 MW) with RO Certificates (ROCs) which they can then sell on. All licensed UK electricity suppliers must have a minimum amount of ROCs, which was 3% in 2002 and increases by 1% each year (Lipp, 2007). If they fail to meet the obligations then they have to buy in electricity at £30/MWh. There are now different ROC bands for roof-mounted and ground-mounted medium size PV arrays. However the UK government's recent year-long review of the RO banding has created uncertainty in the sector (EREC, 2013).

In April 2006 the Low Carbon Building Programme (LCBP) began, where grants contributed to the cost of renewables in development. It had a high uptake and this led to a review of the financial model with the industry in April 2007. It was then re-launched in May 2007 with changes to the grant system. In July 2009 the FiT system was announced, and the LCBP closed in April 2010 when the FiTs came into place. The FiTs were unlike previous subsidy programmes as they provided a minimum payment for each kWh of electricity generated and an additional tariff for any electricity exported. These payments are above the market price, ensuring that even the smallest generators can connect to the grid and sell their electricity (Sawin, 2004). The price is fixed for 25 years for PV, and payment received depends on the size of the array and rates are Retail Price Index (RPI) linked. FiTs therefore reduce the risk of upfront capital investment because of the guaranteed rates of return. They are financed through a levy on all electricity bills (Post Solar PV, 2012). Analysis of the different forms of subsidy implemented have identified FiTs as the most effective tariff mechanism to support renewable energy (Mendonça, 2009; Mosher and Corscadden, 2012; Couture and Gagnon, 2010). However good design and stability are essential for FiTs to deliver maximum benefits (Couture and Gagnon, 2010), particularly rapid capacity growth (Gipe, 2011). Most PV cells have a 25-year manufacturer warranty and an expected system life of around 40 years (The Central Association of Agricultural Valuers, 2010), so even after FiT payments stop, arrays will still be generating an income.

The history of FiT policy in Britain has been marred by controversy and uncertainty. In August 2011 there was an unexpected and large decrease in the FiT rates, due to higher than predicted uptake (Evo Energy, 2012). In December 2011 DECC announced the value of the new FiT rates before the end of the industry consultation period (ibid). This caused widespread uncertainty in the PV industry. The PV industry immediately took action against the government, taking them to the High Court, who ruled that DECC had acted unlawfully by announcing the FiT rate cuts prematurely (ibid). A government appeal against this ruling was lost in January 2012 and the FiT rate cuts were delayed until March 2012 (ibid). In May 2012 DECC revealed a quarterly planned FiT rate degression, based on a regular percentage reduction that was dependent upon installed capacity. This was designed to promote a predictable and stable environment that allowed sustainable cost reduction and was implemented from November 2012 (Energy Saving Trust, 2012). Although it is acknowledged that FiT rates that are too high are a burden on society and promote inefficient renewable projects (Klein *et al.*, 2008), in this case the degression caused a severe decline in confidence in the industry and the government has been widely criticised for this (EREC, 2013).

PV was included as a key technology in the government's Renewables Roadmap for the first time in 2012 (DECC, 2012a). DECC published the first part of a full Solar Strategy in 2013 (DECC, 2013b) and the full roadmap in April 2014 (DECC, 2014a). They have modelled that the PV industry could install between 7-20GW of solar by 2020 (DECC, 2012a). However the report does include the caveat that top deployment figures can only be reached if costs decrease and issues with the grid network are resolved (POSTNOTE, 2012).

3.1.2 Land Tenure

Only a small proportion of the UK population are landowners, a result of historical processes. The Enclosure Acts, passed mainly between 1720 and 1840, led to previously open and common land becoming enclosed and land ownership being transferred to private individuals. Apart from land owned by the state such as Ministry of Defence sites, and small portions of communal land, the majority of land is now privately owned (Home, 2009). It has been estimated that 69% of land in the UK is owned by 0.6% of the population (Cahill, 2002), as many landed estates are passed down through family generations and their integral structure is maintained.

Many of these large estates incorporate several farms, with only 37% of farms in Britain owned by the occupier. 16% are solely rented from a landlord, and 47% of farms have mixed tenancies (Farm Business Survey, 2011/2012). The decision to invest in the farm business is complicated further if the farm is rented, particularly with PV arrays due to their long lifespan. However the different types of agricultural tenancies can alter what effect they have on the process of installing a PV array. Tenancies can be either Agricultural Holdings Act (AHA's) or Farm Business Tenancies (FBT's). The Agricultural Holdings Act (1948) gave existing and future tenant farmers security of tenure for life and potential for succession for three generations. (This provision was extended in 1976 to allow close relatives of a deceased tenant to take over the holding on the same terms.) Tenancy agreements made after 1st September 1995 as part of the AHA are known as FBT's and give landlords and tenants freedom to negotiate tenancies that suit the needs of both parties. Stipulations include that part of the tenanted land must be farmed throughout the life of the tenancy, and that tenants can only diversify away from agriculture if this is agreed in the original tenancy. Tenants can be compensated for improvements to the farm as long as the landlord has given consent for them to be made and is in agreement. This means that farmers can install PV arrays and it is possible for them to be compensated for the capital invested if the farm and array are then passed on to another tenant (Defra, 2012a).

3.2 Existing Statistics on Farmers/Landowners and Renewable Energy

Current academic research is centred on the scientific and engineering aspects of PV. Very little research has been done on the social element once the technology has been deployed, even less with a focus on farmers and landowners, with the exception of a few studies on wind turbines in Aberdeenshire (Bell and Booth, 2010; The James Hutton Institute, 2012); Sutherland *et al.*, 2012). Mosher and Corscadden (2012) highlight that research into individual sectors is beneficial to explore. To date the only data available on renewable energy in British agriculture have been from surveys in the grey literature. A survey by the NFU and NatWest projected that 30% of farmers across England and Wales will be involved in some form of renewable energy production, use or supply by the end of the summer 2012, with one in six installing PV (Farmers Weekly, 2012). A Farmers Weekly survey revealed that 76% of farmers believe that renewable energy generation could play a greater role in the future of their businesses (Frazer, 2013). An annual survey by the National Farm Research Unit (2012) found that 28% of farmers without it are considering renewable energy, but this figure has not increased since 2010. 14% of farmers surveyed by the NFRU were planning to install PV technology, the same as in 2011 and up from 6% in 2010. Research by EnergyNow found that 95% of farmers and landowners sampled believe that renewable energy would be vital to the future of farming in the UK, but that 42% were confused about their renewable energy options. Despite this, a high proportion have researched energy solutions (Farmers Guardian, 2013). DairyCo's study of its members found that almost 15% of farmers surveyed had implemented a technology in the past 12 months (DairyCo, 2011). Defra and the ONS (2012) also conducted a survey on renewable energy on farms in 2010. However surveys of this nature often have low sampling numbers which are too small to draw robust conclusions from, and are not always sampled randomly. Also analysis for statistical significance is rarely done.

3.3 Farmer Decision-Making

Farmer decision-making became the focus of much behavioural research in the 1970s and 80s, and has recently been revisited in light of interest in the uptake of agri-environment schemes (AES) and the recognition that decisions made on the farm often have a large influence beyond the farm gate (Edwards-Jones, 2006). Policy makers and academics became interested in farmer behaviour after several schemes designed to discourage overproduction in farming were unsuccessful despite low farm incomes (Burton, 2004). Generally, the view that farmers make decisions purely based on economic factors has been succeeded by the view that these processes are affected by a variety of different factors, and that attitude does not directly relate to behaviour (Burton, 2004; Wallace and Moss, 2002; Willock *et al.*, 1999; Holloway, 1999). Elements of social science and psychology are being brought into this area of research (Edwards-Jones, 2006) especially when it comes to modelling uptake of new technologies (Sheikh *et al.*, 2003). This is where the behavioural approach can help to analyse uptake of PV technology in the farming sector.

Burton (2004) describes the behavioural approach often used in these studies, where an actor-orientated questionnaire is used as the main method to explore the motives, values and attitudes that determine the decision-making processes of individual farmers. In this paper he argues that behavioural approaches in agriculture could benefit from incorporating Ajzen's theory of planned behaviour (Ajzen, 1991), a conceptual framework which brings in socio-psychological theory and takes greater account of normative influences (the peer-pressure of conformity).

Figure 3-2. Ajzen's theory of planned behaviour (Ajzen, 1991), taken from (Burton, 2004).

One area of research has looked at whether farmers with certain farm characteristics have similar attitudes. For example in Europe, North America and Australasia there has been an increasing trend of polarisation in terms of farm size over the past few decades. Average farm sizes have increased due to larger commercial farming, but there has also been an increase in peri-urban amenity farms (Marsden and Sonnino, 2008). Research by Blackstock *et al.* (2010) showed that larger farms are concerned with profit and competitive advantages, whereas smaller farms rely on off-farm income schemes such as agri-environment schemes. Although diversification is more likely on larger farms (McNally, 2001), Sheikh *et al.* (2003) considers farm size as one of the most important influences of farmer decision making. Other influences on farmer decision making include age, education, cultural, institutional and peer-pressure influences (Edwards-Jones, 2006; Blackstock, *et al.*, 2010; Sheikh *et al.,* 2003). Overall they concluded that farmer decision making is a complex, multi-faceted process on which other farmers have a strong influence. They also noted that when it comes to mitigation strategies, the farming community is heterogeneous and therefore multiple forms of knowledge and communication are needed (Blackstock *et al.*, 2010).

In recent years much farmer behaviour research has been based around understanding the uptake of AES. A study by Vanslembrouck *et al.* (2002) of Belgian farmers found that younger and better educated farmers were more positive about AES', and those with previous experience or whose neighbours have experience of AES are also more positive. They also found that participation rates can be increased through education and demonstration projects. Wilson and Hart (2000) conducted a European wide study, finding similar results in the sense that economic factors were not the sole determinant of uptake, and that findings from other UK studies were reflected elsewhere in Europe. Very little work has been done on the behaviour of land managers (for example estates or public sector bodies) as compared to farmers (The James Hutton Institute, 2014). No work has yet been done on farmer behaviour in relation to uptake of renewable energy technologies, and whether this is similar to that seen in AES schemes.

3.4 Drivers of PV Uptake

Like any business investment, the decision to consider installing renewable technology on a farm will not be made lightly. A variety of reasons may be behind this decision, but two main themes emerge from literature on farmer decision-making: finances and the environment.

3.4.1 Financial Drivers

The return on capital from PV arrays is highly variable depending on the specifics of a particular array, but a recent survey in the grey literature found that 71% of farmers felt that renewable energy provided a good return on investment (ROI) compared to farming (Frazer, 2013). However little is known about the threshold of ROI needed before the decision is made to invest. The ROI is made up of a combination of FiT payments, money saved from electricity bills and any additional payments from exporting electricity. The basic FiT payments and extra export tariffs are fixed for twenty years. Energy costs can also be a driver for the uptake of PV. Farming enterprises such as dairies have a high electricity usage, and external energy prices have been increasing rapidly in recent years (The Telegraph, 2013). Producing their own energy means farmers reduce their reliance on external companies and are producing electricity at a fixed and often lower cost. The advantages of PV in particular are also maximised by many farms, because they have a high energy usage during the day, and/ or during the summer, such as grain stores. It is advantageous to use PV generated electricity during peak generation times as it cannot be stored commercially yet (although research is on-going, see Nottrott *et al.* (2013)) and must be exported to the grid otherwise.

For example the benefits to poultry farming could be large, as a vast amount of electricity is used for ventilation, cooling and lighting of poultry houses. Poultry accounted for 11% of UK agriculture output value in 2011, and electricity costs account for 15% of GVA from this industry compared to cereals where the comparative figure is 3% (CCC, 2013). PV can also help to reduce the impact of electricity price rises- which have been projected to erode profits for energy intensive farming activities in England by around £30 million by 2030 (CCC, 2013). Farm type may therefore have an influence on financial reasons for installing PV. A Defra and ONS (2012) survey showed that horticultural (7.3%) and mixed farms (6.7%) had the greatest share of renewable energy. This may be because these farm types use large amounts of electricity. In horticulture this is used for maintaining controlled environments, and in mixed farming it is used for livestock facilities such as the rearing of poultry or milking parlours.

Farmers/landowners may be installing PV arrays because they wish to diversify the farm business without detracting from the agricultural side. With ground mounted PV arrays, if the land is still being used predominantly for agricultural activities all year round then it is still eligible for the Single

Payment Scheme (SPS). The SPS is the main part of the EU's CAP scheme and is an agricultural subsidy for landowners that is not based on production but on hectares of land. To receive this subsidy, landowners must meet Cross Compliance rules, which include keeping the land in Good Agricultural and Environmental Condition (GAEC). If animals such as sheep or geese are free to graze the area under the solar panels without difficulty then this area may still be eligible for SPS. However the parcels of land taken up by the solar panels' supporting mast or hard standing must be declared and deducted from any claim. Without any grazing, the whole land parcel will be ineligible for SPS. Another consideration is the time taken for installation of the solar array. If the agricultural use of the land is disrupted during the time taken to install the array, then the land should be excluded from any claim for the year of installation. The land may also count towards the points target for Entry Level Stewardship as long as certain conditions are met (Natural England, 2011).

3.4.2 Environmental Drivers

The literature on farmer behaviour in relation to AES points out that the financial imperative for farmers does not exclude an equally important environmental concern (Wilson and Hart, 2000). This dual concern was also reflected in a renewable energy survey of farmers by CCGroup (2013). The balance of these considerations may be affected by the characteristics of the farmer. The wider literature on farmer behaviour shows that farm size is one of the most important influences of farmer decision making (Sheikh et al., 2003). For example when looking at AES, Blackstock *et al.* (2010) found that larger farms are concerned with profit whereas smaller farms rely on off-farm incomes. A Defra/ONS (2012) survey found that small farms have the highest share of renewables (5.1%), although this was not tested statistically. A study by Vanslembrouck *et al.* (2002) of Belgian farmers found that younger and better educated farmers were more positive about AES. However the Defra/ONS (2012) survey found that farmers in the age group 55-64 years old were more likely to have renewable technologies installed (5.2%). A study by DECC (2012b) on domestic PV arrays showed a higher PV density in areas of low educational deprivation and areas where the average age is 40 or above.

3.5 Barriers to PV Uptake

Mendonça (2009) identified significant barriers to the implementation of renewable energy, which he divides into four categories: financial and market impediments, political and regulatory impediments, aesthetic and environmental impediments and cultural and behavioural impediments. Barriers which fit into the first three of these groups have been identified specifically for PV from the literature, no research into cultural and behavioural impediments has been conducted in this field.

3.5.1 Financial Barriers

Despite the potential for financial returns, PV also requires significant upfront capital investment which can be problematic (Sawin, 2004). An NFU Farm Energy Service survey (Farmers Weekly, 2012) found lack of access to finance a problem for a third of farmers. The average annual cash income of farms in England is approximately £78,000 with a £33,000 management investment income (Farm Business Survey, 2011/2012) which may not be sufficient to cover PV capital costs. It is estimated that as much as 80% of PV projects may be financed by credit (The Central Association of Agricultural Valuers, 2010), although credit may not be available or only available under strict conditions. Therefore many large-scale projects lease land from farmers or use a joint venture model, whereby the developer will raise the funds in the market (The Central Association of Agricultural Valuers, 2010). If adequate infrastructure needed to connect to the grid is not present, then farmers may have to pay thousands of pounds to upgrade their connection (Sutherland *et al.,* 2012), and annual maintenance costs may be in the region of 1% of the capital cost (The Central Association of Agricultural Valuers, 2010), adding to the overall project cost. Uncertainty over FiT rates and political commitment to them (see section 3.1.1) is also a barrier to PV uptake.

3.5.2 Planning

The NFU Farm Energy Service survey (Farmers Weekly, 2012) found that planning permission was cited as the greatest perceived barrier to renewable energy by 50% of farmers who already have renewable technologies. Sutherland *et al.* (2012) found that farmers who have been through the planning process for wind turbines found it complicated, costly and time-consuming. Planning requirements for different PV arrays vary hugely, depending on the size and characteristics of the array and the local area. For example small-scale arrays do not need planning permission as they are classed as 'permitted development'. Arrays on or in the grounds of a domestic or commercial (including agricultural) building are covered under The Town and Country Planning (General Permitted Development) Amendment (England) Order (2012). This applies as long as the conditions of this order are met, such as: panels must not protrude greater than 20cm above the roof, the visual effect on the building must be minimized, ground arrays must be less than 9m^2, they must not be within a National Park or other designation, or on a listed building. If planning permission is required, then both communities and local government must be in support of the project for it to go ahead, however the national planning rules in this area are not explicit and have to be interpreted by the local authority.

National planning policy guidance explains that all communities have a responsibility to increase the supply of renewable energy, but this does not mean that the need for renewable energy automatically overrides environmental protections and the planning concerns of local communities (DCLG, 2013). There is also no national guidance on the planning fee category specifically for PV installations (Ownenergy, 2011). For example Cornwall County Council, who have extensive guidance on PV array planning, ask for a £335 planning fee for submitting a medium-scale (4-

50kW) PV array application, with a rate of £335 per 0.1ha for large-scale ground arrays. An average 5MW array would require £26,565 in planning fees (Cornwall County Council, 2012). Overall the planning process is often perceived as being complicated and costly.

3.5.3 Community Opposition

A survey by Farmers Weekly (2013b) found opposition from family/community one of the top five barriers to on-farm renewable energy generation. On-going research from the James Hutton Institute has compared renewable energy production in Scotland, Germany and Czech Republic and found that opposition from local/pressure groups is a common barrier to implementation. Communities usually object over grounds of insufficient infrastructure and the development being disruptive to the landscape, particularly visually. However this research found that Scottish farmers have become much more pro-active about discussing their plans with the local community before seeking planning permission. This approach is suggested by Cornwall County Council (2012) as best practice for PV arrays. DECC’s public attitudes tracker shows that, with 85% public support, PV may be a key technology in engaging people with renewable energy (DECC, 2013a), rather than being a divisive issue like onshore wind turbine developments (Rygg, 2012).

Little work exploring the community response to renewable energy has been undertaken. Roaf (2007) postulates that renewable energy can act to unite communities, which increases resilience and also community preparedness for climate change and energy price rises. On an individual level taking responsibility for energy production could possibly empower people as agents of change. BRE (2014) suggest that making biodiversity enhancements can increase community engagement with solar parks.

In Germany local communities have been facilitators of many arrays rather than opponents. By 2009 German farmers owned 9% of total renewable energy sources (German Renewable Energy Agency, cited in Mosher and

Corscadden, 2012) and by 2010, 22GW of PV was installed on barn rooftops (Hambrick *et al.*, 2010). Altogether €1bn is invested in more than 500 co-operative renewable energy projects, the majority of those involving farmers. Support from farm co-ops and lobbying groups and rural community engagement have been a major factor in facilitating this renewable trend in Germany. Local 'Maschinenringe', farmer machinery syndicates, support renewable energy and often bulk buy solar panels for farmers. The Federation of German Farmers has also been quick to lobby for renewable-friendly policies. There is also a very localized attitude in rural areas, with many seeing 100% renewable energy generation as extremely desirable (Hambrick *et al.*, 2010). This grass-roots approach has been identified as one of the main reasons for Germany's success in renewable energy (Lipp, 2007).

In contrast, there are only 40 co-operative energy projects in the UK with a total value of £16m (Farmers Weekly, 2013a). There are both community owned PV schemes, such as Westmill in Oxfordshire, and farmer-farmer cooperative schemes, such as the advisory company 7Y Energy which is owned by 450 farmers (The Guardian, 2010). Farmers in Wales have committed to funding a community scheme worth several hundred thousand pounds with profits from their wind farm, although it is yet to be built (Forum for the Future, 2011). Community-gain schemes may be a successful way to trade-off any negative effects of a development. However, for reasons unexplored, this grass-roots approach does not appear to have taken off in Britain.

3.5.4 Access to Information

Access to information in order to make informed choices was identified by the NFU Farm Energy Service (Farmers Weekly, 2012) as the third most significant barrier for renewable energy by farmers. Informed choices need to be made about issues such as array location, size, ownership vs. renting, landlord/tenancy issues, suppliers, installers and insurance. Many farmers may have limited access to a reasonable internet connection and may have few IT skills (86% of farmers in England have a computer but 2% of these don't have an internet connection (Defra/ONS, 2013), and internet sources cannot always be trusted for impartial advice.

3.6 Impacts of PV Arrays

It has been claimed that renewable energy is a win-win scenario for farmers (Wolfe, 2006) but little research into the impacts have been done. No study has yet looked at the financial impacts of renewable energy on farmers. Some work has been done on the financial benefits of wind turbines in Aberdeenshire (Bell and Booth, 2010), but was completed just as the FiTs were introduced and the calculations are therefore out of date.

3.6.1 Environmental Impacts

There is also little scientific evidence of the environmental impacts of PV arrays, despite all solar farms having to have a biodiversity management plan (BRE, 2013). Natural England (2011), the RSPB (2011) and BRE (2013) have produced briefing notes detailing their concerns. They state that there is no evidence of PV arrays significantly harming birds, citing McCrary *et al.* (1986) as evidence. They also highlight that field arrays can result in less intensive use of grassland, which in turn may increase biodiversity, as is the aim in the Kobern-Gondorf area of Germany (RSPB, 2011). The only existing evidence of this is a small-scale and unpublished study, which found that in some circumstances biodiversity (as measured by herb, bumblebee and butterfly counts) can be increased in solar parks, particularly if they are planted with wildflower mixes. It is also recommended that buffer strips of 4m or more are left between the array and the hedgerow in order to allow access and encourage biodiversity (Cornwall County Council, 2012). Grazing of animals such as geese or sheep under ground-mounted solar arrays is encouraged as it is synergistic. It keeps land productive for agriculture and also prevents plant growth that would shade the panels (Cornwall County

Council, 2012). PV arrays are also not permanent, so land can be converted back to its original use as it will not have been altered significantly. Only 30% of the ground is covered by the panels, and the lack of human management can allow wildlife to flourish (BRE, 2013). The most recent industry guidance on solar parks suggests that carbon storage may also increase in post-agricultural land (BRE, 2014), however no research has been conducted to explore this.

The RSPB are concerned that insects that lay eggs in water may mistake solar panels for water bodies due to the reflection of polarised light. Under certain circumstances insects have been found to lay eggs on their surfaces, reducing their reproductive success and food availability for birds (Horváth *et al.*, 2010). Populations of these insects could therefore be affected, having a knock-on effect in the food chain. The RSPB therefore does not recommend having solar panels close to water bodies in important ecological sites. They also have concerns about security fencing reducing animal mobility, the moving parts on sun-tracking arrays posing a risk to animals and the possible loss of habitat in some cases (RSPB, 2011).

PV arrays can have a range of impacts on a landscape scale. The height of the array (if field-based) is usually kept to below 4m in order to rise no higher than surrounding hedgerows. In flat areas the visual impact can therefore be almost nil, but if topography is variable then the array may have a large visual footprint. PV arrays do not create any wind turbulence, and are designed to absorb radiation so very low levels of glint or glare are given off. The only noise or vibration occurs immediately adjacent to the inverters as they require a cooling fan, but this is imperceptible beyond the array itself. Air quality is not affected as there are no emissions from arrays, levels of traffic to the site only increase during installation and annual maintenance, and arrays do not cause changes in surface water runoff (Ownenergy, 2011). A well designed PV array may have virtually no impact on the surrounding landscape at all.

3.6.2 Impact on Farmer Behaviour

Previous research suggests that having a renewable energy array may impact on farmer behaviour. A survey by the PR firm (CCgroup, 2013), although not an academically rigorous piece of research, found that those who had already installed a renewable technology were more receptive to thinking about installing another. A similar survey found that 75% of those who were already generating renewable energy were likely to invest again in the future (Frazer, 2013).

3.7 PV Arrays and Carbon

The theory behind renewable energy technologies reducing CO_2 emissions are based on the fact that electricity produced this way displaces electricity produced by traditional fossil fuel based methods. CO_2 is emitted during the manufacturing and transport of the PV panels themselves, but once they are installed they need little maintenance and for the lifetime of the panel no CO_2 is emitted. However pinpointing and quantifying the overall CO_2 emissions of a PV panel can be complicated and have large errors involved (DECC, 2013b). A life cycle analysis approach has been used to try and quantify an average range of $kgCO_2e$ per kWh for PV, however methods and assumptions can vary between different life cycle analysis (Hsu *et al.*, 2012). For the most common silicon-based PV panels, 60-80% of CO_2 emissions come from mineral extraction and manufacturing. This is an energy intensive process and requires a variety of other metals to complete. Figure 3-3 shows the relative CO_2 emissions from the different stages of a PV panel lifecycle.

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Figure 3-3: The CO_2 emissions associated with different life cycle stages of PV (NREL, 2012).

The averaged figure for CO_2e emissions per kWh are highly dependent upon a number of variables. As well as the precise figure being dependent upon the different methods of construction for the panels, it is also dependent upon the efficiency of the panel in its lifetime. This is affected by the amount of solar radiation the panel receives, which in turn is affected by where the panel is located. Table 3-1 below shows the difference in gCO_2e per kWh for grid electricity and PV.

Electricity Generation	**gCO_2e per kWh**
Grid electricity	445.48 (Carbon Trust, 2013)
PV	40 (NREL, 2012)
PV	57 (median of meta analysis, (Hsu, *et al.*, 2012)

Table 3-1: Average gCO2e per kWh for grid electricity and PV.

3.8 The Need for Further Research

This literature review has assessed a range of research which relates to farmers and landowners' uptake of PV arrays. The wide range of factors involved and the speed at which the renewable energy industry is developing, highlights how an interdisciplinary approach to this research is required.

The agricultural sector has been asked to reduce their emissions by 11% by 2020 (Farming Futures, 2010c) in response to the UK and the EU setting out emissions reduction targets in order to mitigate the effects of anthropogenic climate change. Despite a parallel objective to source 15% of the UK's energy from renewable sources by 2020 (European Parliament, 2009), little work has been done on the crossover between agriculture and renewable energy. Previous and on-going academic research has focussed on the scientific and engineering aspects of these technologies, so there is a significant lack of social research into how these technologies become incorporated into society. Patterns and trends need to be identified in order to aid our understanding of renewable uptake in non-domestic settings.

Previous research which this thesis will build upon includes that of Mosher and Corscadden (2012) who identify a lack of research into renewable energy in the agricultural sector. The first specific research theme which has been identified in this literature review is of drivers of PV uptake amongst landowners. The research will explore whether drivers are mainly financial (as suggested by Sutherland *et al.* (2012)) or environmental, and if the two are not mutually exclusive, as Wilson and Hart (2000) concluded. Previous research by Blackstock *et al.* (2010) found that farmer behaviour correlated with farm size, as larger farms were concerned with profit whereas smaller farms relied upon off-farm income schemes. McNally (2001) also found that diversification is more likely on larger farms, however a Defra/ONS (2012) survey found that small farms have the highest share of renewables (5.1%). Further research is also needed to explore the results and themes identified by surveys recorded in the grey literature (Farmers Weekly, 2012; Farmers Guardian, 2013; Frazer, 2013; DairyCo, 2011; Farmers Weekly, 2013b). Apart from the survey by DairyCo (2011) which looked specifically at dairy farmers, the difference in renewable trends between different agricultural sectors has not been explored, despite there being vast differences in electricity trends between different farm types. Trends of domestic PV installations being influenced by age and educational status (DECC, 2012b) will be explored in a farming context. The Defra/ONS (2012) survey found that farmers in the age group 55-64 years old were more likely to have renewable technologies installed.

The second theme of this research which needs exploring is that of barriers of PV uptake. This thesis will also explore further the barriers to renewable energy identified by Mendonça (2009) in order to determine their relative influence. This includes those of peer-pressure influences, as highlighted by Edwards-Jones (2006), communication and information issues as have been highlighted by CCgroup (2013), and upfront capital investment which can be problematic (Sawin, 2004).

This research will also explore the impact of PV arrays on farmers/landowners and their land, for example determining the actual ROI that farmers/landowners are getting, further to the results of Frazer (2013) who found that 71% of farmers felt that renewable energy provided a good ROI compared to farming. It will also seek to corroborate on-going research at the James Hutton Institute that indicates that farmers are becoming more pro-active about their interactions with the local community when it comes to renewable energy generation, and that farmers who have one renewable technology installed are more likely to install other types (Farmers Weekly, 2013c; CC Group, 2013). It will also explore the assertion by Roaf (2007) that renewable energy can unite communities, as well as exploring whether farmers/landowner attitudes to the environment and climate change have altered since installing a PV array.

This literature review has demonstrated the need for the agricultural industry to mitigate its GHG emissions in the face of increasingly dangerous climate change, and that this movement may not be driven from the international community down but also needs to be driven from the bottom up. Although the agricultural industry is not the main GHG emitter, it is uniquely placed to be at the forefront of the PV industry and to benefit the most from it. However it is apparent that there are significant barriers for many farmers/landowners who want to utilise PV and there could be many lessons learnt from studying those who are already exploiting this technology. The aim of this research is to therefore explore how PV has been taken up in agriculture, but before the methodology is presented a conceptual framework for this study is provided.

3.9 Conceptual Framework

A conceptual framework allows issues to be organized in a logical way and to identify relationships between different concepts. The concept for this research is organized around the Theory of Planned Behaviour (TPB) (Ajzen, 1991) (see section 3.3), because it has been widely used in conservation-related farmer behaviour studies (Lynne *et al.*, 1995; Beedell and Rehman, 2000).

Figure 3-4 shows the conceptual framework based on the TPB. In this context, the attitude is that the farmer/landowner wants to explore installing a PV array. This may be driven by either, or a mixture of, environmental and financial concerns, which in turn can be affected by age and education of the farmer/landowner. The subjective norm is how the farmer/landowner thinks other people will judge them for this behaviour. The role of communities, both farmer and non-farmer, feed into the subjective norm, as renewable energy in particular can be controversial and provoke ideological protests from communities. Perceived behavioural control is whether or not the farmer/landowner thinks they can achieve the desired outcome of the behaviour. The ability of the farmer/landowner to make decisions is affected heavily by the quality of information available to them about their options.

The intention is that the farmers/landowners would like to install a PV array, but this is influenced by both internal and external factors. Internal factors include the farms financial situation, which may prevent them from gaining credit, farm type and farm size, both of which may affect the payback period of the array. External influences include energy costs, the return on investment, availability of finance, ease of grid connection, current FiT policy and rates and current planning issues. These external factors in particular combine to define the level of risk involved with the farmer/landowner acting on his intention, which may ultimately hinder or prevent this action altogether.

Figure 3-4: Conceptual diagram based on Ajzen's (1991) theory of planned behaviour.

3.10 Research Questions

Based on the research objectives, the literature review in chapters 2 and 3 and the conceptual framework, a number of core research issues and concise questions have been identified.

1. Are there any common characteristics of the farms with PV arrays and the farmers/landowners which install them?
2. What are the motivations behind farmers installing PV arrays, and have their farming decisions altered since installation?
3. What impacts do panels have on the farm environment and farm business?
4. What are the barriers to more farmers/landowners installing PV and how can these be overcome?

In order to address these research questions, an appropriate methodology has been selected. The following chapter provides a detailed explanation of the methods used, their rationale and implementation.

Chapter 4. Methodology

4.1 Introduction

The research strategy and methods used in this study were selected with careful consideration of the research objectives, as outlined in section 1.2. Following on from the research objectives, a detailed review of the literature in chapters 2 and 3 has identified four research questions (see section 3.10). However because very little academic research has been done on the relationship between farmers/landowners and renewable energy, there are no directly comparable studies or methodologies which can be applied to this research. Instead the wider literature of farmer behaviour in relation to AES and new technology uptake was drawn upon (Läpple and Kelley, 2010; Garforth and Rehman, 2006; Rehman *et al.*, 2007). It was therefore decided to use a methodology which provided the opportunity to collect as much data as possible in order to begin identifying patterns and areas of interest. The methodology consisted of a large-scale questionnaire of farmers/landowners who already have PV arrays, combining both qualitative and quantitative questions in order to provide representative data suitable for statistical analysis. The aim of the quantitative data was to create a farmer segmentation model based on different attitudes and values associated with PV arrays. The aim of the qualitative data was to provide further detail on aspects important to the respondents, and to provide further evidence to complement the quantitative data. The methodology is described below. This chapter also identifies difficulties arising from the research design, outlines the ethical considerations and also the data analysis techniques used.

4.2 Mixed Methods Approach

A mixed methods approach was decided upon, using both quantitative and qualitative techniques. Mixed method approaches have grown in popularity in the last decade, it has become known as the 'third research paradigm' (Johnson and Onwuegbuzie, 2004, cited in Creswell and Planco Clark, 2010:

3). Tashakkori and Creswell (2007, cited in Creswell and Planco Clark, 2010: 4) define mixed methods research as:

‘research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or a program of enquiry’.

Creswell and Planco Clark (2010) state that the use of a mixed methods approach can provide a better understanding of the research problem than either approach alone. Jick (1979) likens this method to that of triangulation, as it serves to increase the accuracy of research (Gillham, 2007).

Both quantitative and qualitative methods have their own benefits and assumptions (Denscombe, 2010). Quantitative methods involve the examination of responses to pre-determined questions, whereas qualitative methods give a detailed understanding of the research issues through exploring experiences and meaning. Both methods have their limitations as well though. As this study forms part of a new area of research, a mixed method approach provides a good base for exploration of the issues and collection of data alongside examining the causes behind any significant patterns found (Creswell and Planco Clark, 2010). Providing the opportunity for the elaboration of important issues allows as much information as possible to be collected on the population in question.

There are several methodological frameworks within mixed methods studies, which can be either concurrent or sequential. This study used a concurrent triangulation design shown in Figure 4-1. Both quantitative and qualitative data was collected and analyzed in parallel, through the use of a postal survey. The rationale for this is to increase completeness and give a more comprehensive account. This research used pragmatism as an umbrella philosophy (Creswell and Planco Clark, 2010).

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Figure 4-1: Triangulation design of the methodology (Creswell et al., 2008: 68).

4.3 Ethics

No special ethical considerations had to be made for this research, as the issues explored were not sensitive in nature nor were the respondents part of any high risk category. However the covering letter for the survey did stress the anonymity and confidentiality that the respondents were entitled to, and outlined how this was ensured. All survey responses were given unique identification numbers in order to preserve anonymity, as were the interview transcripts. The research was carried out in line with both the Royal Agricultural University's and the University of Coventry's ethics principles.

4.4 Methodology

The first part of the data collection is a survey aimed at farmers and landowners who already have PV arrays installed on their land. Due to the lack of general statistics and previous academic research on farmers' interaction and experiences with renewable energy, the research priority was to gain as much information as possible about the survey population. A postal survey is a fast and efficient means of gathering data, and was therefore chosen as the main methodology for data collection. Using an online survey would exclude farmers/landowners who do not have an internet connection (86% of farms in England have a computer but 2% of these don't have an internet connection (Defra/ONS, 2013)) or check email regularly. A telephone survey would require significant time resources to complete for the sample required. A postal survey also allows respondents to provide answers at a time most convenient for them, which is important as many farmers/landowners will work long and irregular hours. It also enables a geographically spread out sample to be reached. Although PV arrays tend to be concentrated in the South West, this survey aimed to reach all known farmers/landowners with PV arrays in Great Britain. (Energy policy is devolved in Northern Ireland and the FiT scheme is not available, therefore Northern Ireland is not included in this study.)

4.4.1 Survey Development

Survey development was informed by the literature explored in chapters 2 and 3. This determined which questions needed to be asked and which issues could be explored in the survey. These included core themes such as attitudes, behaviour, social context and perception as well as internal and external influences. Initial scoping interviews with farmers/landowners could not be completed prior to survey development due to time constraints.

The survey began with some general questions in order to establish characteristics of both the respondent and the farm. It then went on to ask questions about the PV array itself and the electricity generated by it, including any changes in land use (if the array was ground-mounted). The survey then went on to ask if the respondent agreed or disagreed with a series of statements, based around financial and environmental attitudes, personal and farm business changes since PV installation, barriers to installation, social influences and their own abilities. Some of these themes were drawn from the TPB model. The following section dealt with the likelihood of future renewable energy engagement and the survey finished with questions on financial aspects of the PV array. There was also a section for further comments at the end in order to allow the respondent to add in anything they felt was not covered by the survey.

Closed questions were used for speed of filling in the survey, for example:

What is the age of the primary farmer or farm manager?

25 or less		51-75	
26-50		75+	

Figure 4-2: Example of a closed question used in the survey.

Open questions were used where necessary:

What is the approximate size of your farm?

______________ acres/hectares **(please delete as appropriate)**

Figure 4-3: Example of an open question used in the survey.

The full survey is shown in Appendix 2. The survey was ten pages long and was printed double-sided with a clear layout and heading. A cover letter was also included in the envelope giving the respondents instructions and explaining the aims and importance of the research (Appendix 1).

The statements where farmers/landowners choose their level of agreement were on a five point scale from strongly disagree to strongly agree. This is a Likert scale, a bipolar scaling method measuring either positive or negative response to a statement (Kent, 2001), and this was used in order to give suitable data consistent enough for statistical analysis. Previous studies on farmer behaviour and attitudes have used this methodology in order to group farmers into different categories depending on the pattern of their answers (Läpple and Kelley, 2010; Garforth and Rehman, 2006; Rehman *et al.*, 2007). The characteristics of the farm and farm manager were then used to describe these farmer types.

The disadvantages of using a survey as a data collection technique are that it gives little scope to probe answers further, or to clarify ambiguous, misleading or inaccurate answers (Dillman, 1991) and they can also have very low response rates. A low response rate can lead to non-response bias and therefore every consideration was given to how to increase the response rate. The best way to improve the response rate of postal surveys is to avoid badly worded and designed surveys. Advice was taken on this from Oppenheim (1992). Questions were kept as simple as possible, avoiding flamboyant language. The layout was well-spaced and designed to be easy to follow, and headed paper was used to demonstrate the University source as this can help response rates (Pennings *et al.*, 2002). Any sensitive questions about finance were left to the end of the survey in order to prevent them from putting people off filling out the rest of the survey (Gillham, 2007). The design went through an iterative process before piloting in order to improve clarity and avoid measurement error (Dillman, 1991).

4.4.2 Piloting

The survey was piloted by sending to a knowledgeable academic who also is a farmer with a PV array, and ten farmers/landowners local to the University who have got PV arrays. This was so that the likelihood of them filling out the survey promptly was increased. The cover letter explained that the survey was being piloted and that there were supplementary questions at the end of the survey for this purpose. Questions were asked on the how long the survey took to complete, how clear the questions were, how relevant they were, any topics that they felt were left out and if they had any other comments. The time taken to complete the survey was given as fifteen minutes by all the respondents, which was not deemed too long.

Two questions were changed in response to comments from the pilot survey. Question 13 was problematic for a few respondents because their PV arrays had only been connected to the grid for a few months. The question was changed to include the option of giving electricity production over a month as well.

13. In the last 12 months, how much electricity was generated by the PV array?

_____________ KWh/MWh (please delete as appropriate)

Figure 4-4: Question 13 in the pilot survey which was altered before the full survey was sent out.

A '*don't know*' option was also added to question 29, in order to establish whether the respondent did not fill out the answer due to not wanting to or whether they just did not know the answer.

If you export some of the electricity, what price are you paid for it?

£ _____________ KWh

Not applicable	

Figure 4-5: Question 29 of the pilot survey which had an additional answer option added in.

The quality of the responses to the pilot survey were good, therefore the survey was deemed not ambiguous and suitable for distribution to the full population.

4.4.3 Sampling Strategy

The sampling strategy was an exploratory one, using a pragmatic approach (Denscombe, 2010). Farmer/landowner contact details were obtained from DECC's renewable energy planning database (https://restats.decc.gov.uk/app/reporting/decc/monthlyextract) and Ofgem's database of accredited PV stations (https://www.renewablesandchp.ofgem.gov.uk/Public/ReportManager.aspx?ReportVisibility=1&ReportCategory=0). These were the only places where addresses of farms with PV arrays were available. However not all farmers/landowners who have PV arrays are on the planning database, due to Permitted Development rights allowing small arrays to be installed without planning permission, and they are therefore not registered on any existing database. A proportion of the population of interest could therefore not be reached and this produced a non-sampling error (Kent, 2001), with a possible bias towards larger PV arrays. To reduce the impact of this effect, farmers/landowners were asked at the end of the survey to voluntarily provide details of other farmers/landowners who the survey could be sent to, a sampling technique described as ‘snowballing’ (Denscombe, 2010).

The survey was sent out to 331 farmers/landowners from across Britain whose details were obtained from the two databases. A further ten surveys were sent out from addresses given using the snowballing technique. To encourage farmers/landowners to return the survey the importance of the study was outlined and they were asked to return the survey by a given date, which was four weeks after mailing. After this date, those farmers/landowners who had not responded, and for which phone numbers were available, were called in order to check whether they had received the survey and if they would be able to complete it. This was done to try and increase the number of returns, as recommended by (Dillman, 1991).

4.4.4 Response Rate

The final response rate for this survey was 27%. This was a very good response rate compared to other surveys of farmers (Britt *et al*. (2011) 17%, Ilbery *et al.* (2006) 11% and Pennings*, et al.* (2002) 12%). The response rate was high possibly because of using follow up calls. Three surveys were returned too late to be included in the analysis. The survey was timed to run after the end of the harvest (Pennings *et al.,* 2002; Ilbery *et al.,* 2006) but before Christmas, in order to maximize the chance of farmers/landowners finding the time to fill it out. Contact details were given to the recipients so that they could call and ask any questions if they wanted to. A pre-paid envelope was included in the postal surveys on the advice of Oppenheim (1992) in order to not pass on any of the cost to the recipients.

4.4.5 Analysis

The quantitative data collected was analysed using a variety of techniques. Tests of difference were used on appropriate data, for example Chi-Square or the Mann-Whitney U Test, to determine if there are any statistically significant relationships between the different factors identified in the survey. The Likert data was subject to factor analysis and then cluster analysis in order to create a farmer segmentation model, as has been done by Pike (2008) and Fisher (2012) (see Appendices 3 and 4 for a detailed explanations of the methods used.) All statistical analysis was done using SPSS software.

Qualitative data collected from the survey was analysed using coding software NVivo. The data was loaded into NVivo, where, through a process of reading the data and the relevant literature, a coding framework was devised and the transcripts coded accordingly. This was done using grounded theory, an inductive analysis technique which uses codes to identify issues and make generalisations (Denscombe, 2010). The qualitative data was gained by asking a series of open ended questions, as well as an open comments box at the end of the survey. The comments are therefore be a mix of prompted and non-prompted ones, which allowed the respondents to bring up issues which they felt had not been covered in the survey, reducing bias.

4.5 Summary

This chapter has outlined how the research questions based on the findings of the literature review were addressed. The methodological approach combined quantitative and qualitative research, in the form of a large-scale postal survey of farmers/landowners with PV arrays. The results of the analysis are presented in the following two chapters.

Chapter 5. Quantitative Data Analysis

5.1 Introduction

This chapter reports the quantitative findings from the postal survey designed to provide data on farmers/landowners in Britain with PV arrays. All 92 returned surveys were used in the data analysis in order to keep the sample size as high as possible, despite the fact that some were missing part of the data. As many of the questions were demanding in the level of knowledge required, and in the level of financial information which had to be divulged, it was made clear to the respondent that they could skip questions if they wished, although they were encouraged to tick '*don't know*' or '*not applicable*' boxes. Therefore many of the respondents did not answer all of the questions. This was unavoidable due to the sensitivity of some of the questions asked. The size of the sample used for each calculation is noted in the description.

This chapter presents the analysis of the data obtained from the survey, beginning with a descriptive analysis of farmer, farm and PV characteristics. It then goes on to explore relationships between key variables before presenting the results of the factor and cluster analysis. Throughout the data analysis process, the data was examined for suitability for the tests used. Issues such as normality were considered and are detailed below. Statistically significant results ($p=<0.05$) are reported, indicating that there is 95% confidence that the null hypothesis can be rejected. Missing data was addressed by using the exclude cases pairwise option in the statistical tests, on the advice of Pallant (2010).

5.2 Descriptive Results

This section provides a broad overview of the data in order to identify relationships to explore further. It starts off with farmer and farm characteristics before exploring the statistics gained on PV arrays. For the purpose of summarising, percentages have been rounded to the nearest percent.

5.2.1 Farmer Characteristics

Almost all of the 92 respondents identified themselves as farmers, one was a farm assistant and three were estate managers. 95% of the farmers who responded were the owners and occupiers of their respective farms (n=88). 97% of the farmers were male (n=88). Just over half of the respondents were aged 51-75 years old, with 42% between 26-50 years old. Very few respondents were beyond retirement age or 25 years old or younger (n=92).

Approximately one quarter of the respondents indicated that either college, diploma or an undergraduate degree was their highest level of education achieved (see Figure 5-1). 16% reached secondary school only and 7% have a postgraduate degree (n=92).

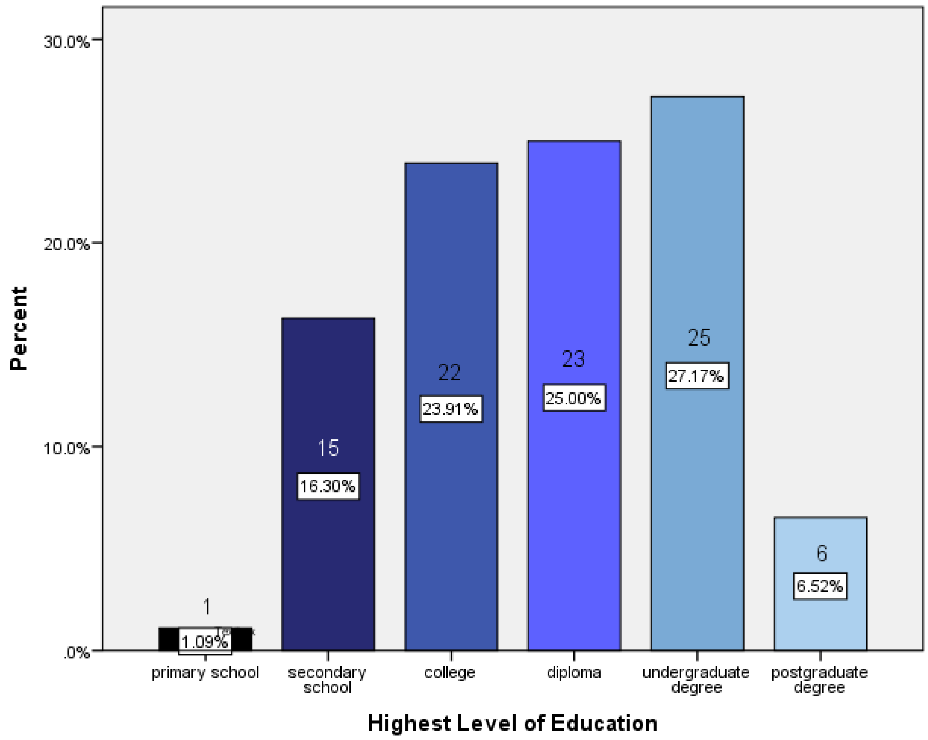

Figure 5-1: Graph to show the highest level of education amongst respondents.

55% of the respondents have 26-50 years experience working in agriculture and/or owning or managing land (see Figure 5-2). Only 5% have less than 10 years experience (n=92).

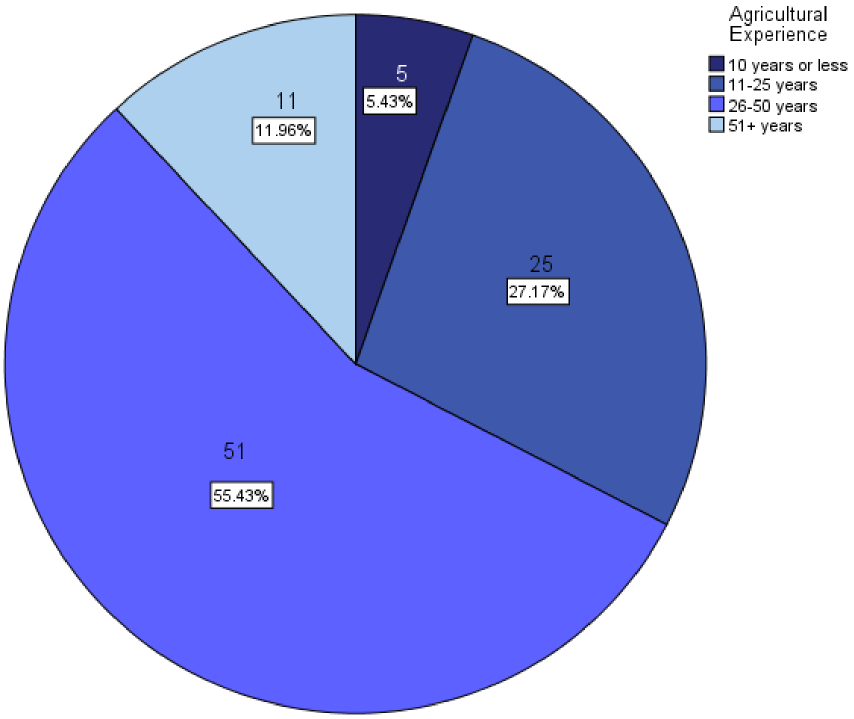

Figure 5-2: Pie chart to show agricultural experience of respondents in years.

82% of respondents owned all of their farms, whilst the remaining 18% have a mix of owning, renting and contract farming their land (n=91).

In order to assess whether these patterns are significantly different from the farming population as a whole, the sample population was compared to the farming population of England, as established using the Farm Business Survey (2011/2012) data, collected by Defra, and other government data (see Table 5-1).

Variable	**Sample n=92**	**Population n=53090** (Farm Business Survey 2011/2012)	**Chi-Square Goodness of Fit Test Statistic**	**P Value**
Gender	Female- 3% Male- 97%	Female- 4.3% Male- 95.7%	0.241	0.623
Highest Level of Education	Primary-1.1% Secondary-16.3% College-24% Diploma-25% Undergraduate-27.2% Postgraduate-6.5%	Primary-0% Secondary-10.8% College-4.7% Diploma-36% Undergraduate-13.8% Postgraduate- 2.5%	127.790	0.000

Table 5-1: Chi-square goodness of fit test for gender and education level.

In order to statistically compare the two data sets, the chi-square goodness of fit test was used. This test allows observed values of categorical variables to be tested against an expected value as given by another dataset (Mehta, 2011).

The difference in gender between the sample and the test population was not statistically significant; however the difference between education levels was highly significant. Whilst most farmers in the wider population have a diploma as the highest level of education, and only 16.3% have an education level above this, in the sample dataset there is a significantly higher proportion of farmers with either undergraduate or post graduate degrees (33.7%). See section 7.4 for a further discussion of this.

5.2.2 Farm Characteristics

Farm characteristics are described below, again followed by a statistical comparison to the overall farming population. Just over half of the farms were situated in the South West of England, followed by East Anglia with 17% (see Figure 5-3). There were very few farms in Wales and none situated north of Yorkshire. Overall 23% of farms were in Cornwall and 18% in Devon (n=72).

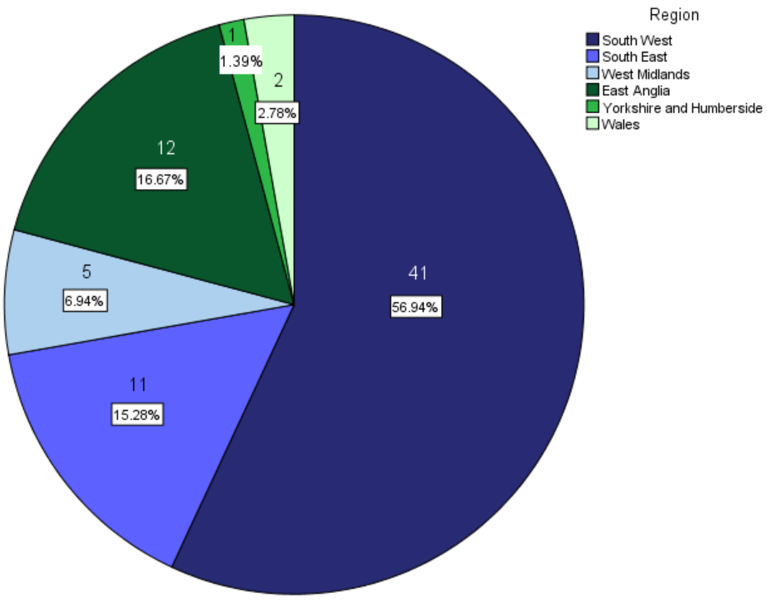

Figure 5-3: Breakdown of respondents' farm location by region.

More than a third of farms who responded are non specific mixed enterprises, just under one fifth are arable and just under a sixth are dairies (n=89) (see Figure 5-4). A Defra and ONS survey (2012) found mixed farms were the second most likely to have renewable energy installed.

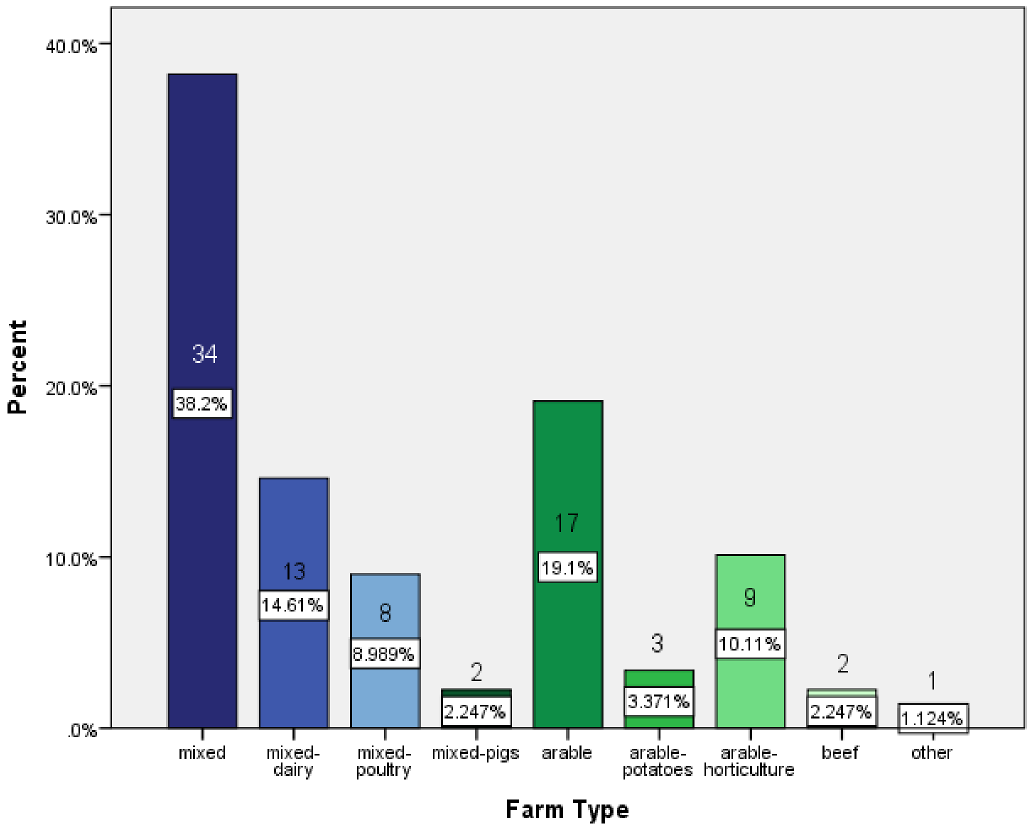

Figure 5-4: Graph to show respondents' farm type.

The mean farm size is 295ha, with a large standard deviation of 473ha (see Figure 5-5). When grouped into size categories as used by Defra/ONS (2012), 33% of farms were from the largest category (200ha +), closely followed by 28% in the 50-100ha category (see Figure 5-6). Only 7% were from the very smallest farms (under 20ha) (n=85).

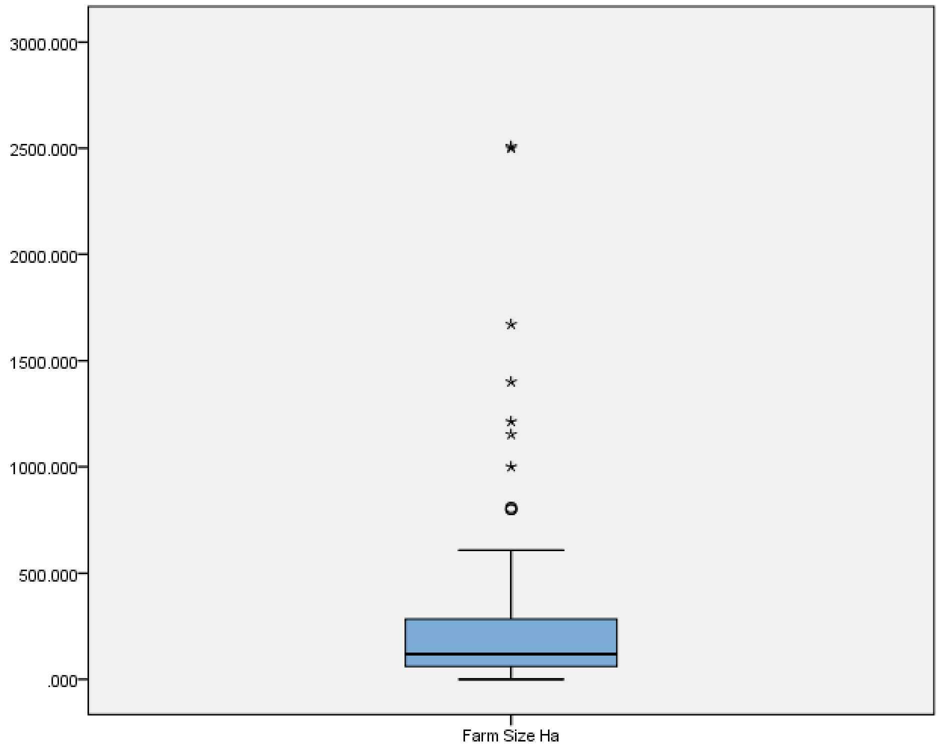

Figure 5-5: Box plot to show the range of farm sizes in ha.

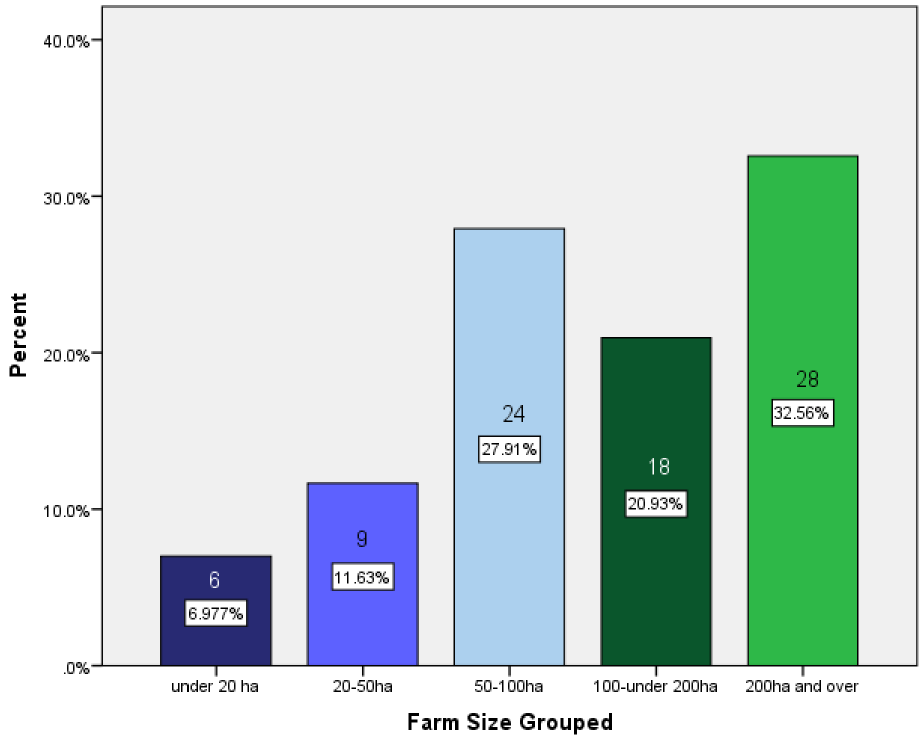

Figure 5-6: Graph to show grouped farm sizes in ha.

84% of the farms belong to the ELS scheme, 23% belong to the HLS scheme and 6% are organic farms (n=73). 45% of farmers business' have a turnover of more than half a million pounds a year (n=65) (see Figure 5-7). Overall 3% selected '*don't know'* for this question, and 26% did not answer (n=92), reflecting the sensitive nature of this question.

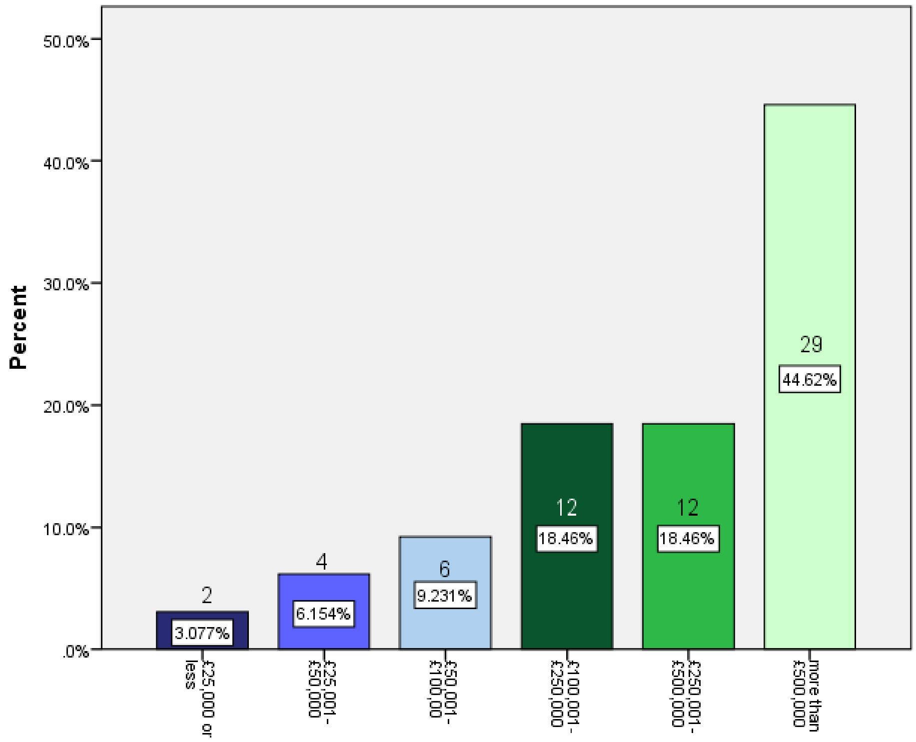

Figure 5-7: Graph to show grouped turnover of respondents' businesses.

The farm characteristics data was also tested for significant differences compared to the farm population as a whole, using the chi-square goodness of fit test (see Table 5-2).

Variable	Sample n=92	Population n=53,090	Chi-Square Goodness of Fit Test Statistic	P Value
Farm Tenure (Farm Business Survey, 2011/2012)	Owned-82.5% Rented-1% Mixed-16.5%	Owned-35.3% Rented-15.9% Mixed-48.7%	89.074	0.000
Farm Location (Farm Business Survey, 2011/2012)	South West-56.9% South East-15.3% West Midlands-6.9% East Midlands-0% East Anglia-16.7% North West-0% Yorkshire and North East- 2.8%	South West-21.5% South East-12.4% West Midlands-9.6% East Midlands-14.1% East Anglia-15.3% North West-12.8% Yorkshire and North East- 14%	34.033	0.000
Farm Type (Farm Business Survey,	Mixed-38.2% Dairy-14.6%	Mixed-43.9% Dairy-13.5%	169.494	0.000

2011/2012)	Poultry-9% Pigs-2.2% Arable-19.1% Potatoes- 3.4% Horticulture-10.1%	Poultry-2.4% Pigs-2.4% Arable-31.6% Potatoes- n/a Horticulture- 6%		
Farm Size (Farm Business Survey, 2011/2012)	Very Small- 7% Small- 11.6% Medium- 27.9% Large- 20.9% Very Large-32.6%	Very Small- 25.7% Small- 28.5% Medium- 15.8% Large- 15.4% Very Large- 14.6%	49.003	0.000
Farm Category (Defra, 2012b)	Organic-5.5% Conventional 94-5%	Organic-13% Conventional-87%	3.651	0.056
ELS Membership (Defra, 2012b)	ELS-83.6% Non ELS-16.4%	ELS-84.2% Non ELS-15.8%	0.022	0.881
HLS Membership (Defra, 2012b)	HLS-23.3% Non HLS-76.7%	HLS-20.5% Non HLS-79.5	0.348	0.555

Table 5-2: Chi-Square Goodness of Fit Test for various farm characteristics.

Significant differences were found in the farm tenure, farm location, farm type and farm size data sets. A significantly larger proportion of farmers in the sample dataset own all of their farmland, and less farmers rented or had mixed tenure farms, compared to those in the wider population. See sections 3.1.2 and 7.5 for a further discussion of this issue.

There were significantly more farms located in the South West than would be expected, but less in the East Midlands, North West, Yorkshire and the North East of England. This is because of higher levels of irradiation received in the South West as well as higher sunshine hours (see section 3.1.1) resulting in more efficient solar arrays and therefore more arrays in the South West. The South West is also very keen to develop a renewable energy economy (Cornwall County Council, 2012), therefore this may also be a reflection of greater investment in the region.

There are significantly more poultry farms and less arable farms in the sample than in the wider population, perhaps because poultry farms have very high electricity costs enabling them to take advantage of the benefits of PV. Arable farms usually occupy high grade agricultural land and/or soil type, and therefore are often reluctant to use fields for PV arrays.

There are fewer very small farms and small farms in the sample than in the population, but more medium, large and very large farms. This may be because large farms have more electricity usage and financial capital than smaller farms, making them more likely to consider and install PV arrays.

5.2.3 PV Array Characteristics

Although some farmers had more than one array, the survey was filled out with the details for just one of these arrays, and the others were described in the comments section at the end. Therefore there were 92 arrays analysed, the same as the number of respondents.

The mean PV capacity of the sampled farms is 2.43MW with a standard deviation of 3.86MW. There is a very large range in capacity, the smallest is

0.002MW and the largest is 18.6MW. 3% of respondents don't know this figure, 2% chose the '*not applicable'* box and 2% did not answer (n=92). Overall there was good knowledge amongst the respondents about the capacity of their PV arrays.

As the DECC Planning Database was used to identify the sample population, and small PV arrays do not need planning permission under permitted development rights (see section 3.5.2), this could have led to a bias towards larger PV capacity arrays in the sample. However the scatterplot (see Figure 5-8) shows a high number of small PV arrays, therefore this bias does not appear to exist.

To test this statistically, the PV capacity of the respondents' farms were compared to the national database of solar array capacities (available from the ReStats website). To determine which test to use, the data were first tested for normality using the Kolmogorov-Smirnov (KS) test (McCrum-Gardner, 2008).

A p value of >0.05 indicates normality of the data. The test statistic for the sample PV capacity data was 0.294 with a p value of 0.000, therefore the data was not normally distributed, and only non-parametric tests can be used. The Mann Whitney U test was used to compare the data from the two datasets (the non-parametric version of independent student's t test (Pallant, 2010)). The Z test statistic was 32040.500 with a p value of 0.094, therefore there is no statistical difference between the two datasets, and the size of the respondents' PV capacities does not significantly differ from national PV arrays as a whole, confirming that there was no bias in the sample selection.

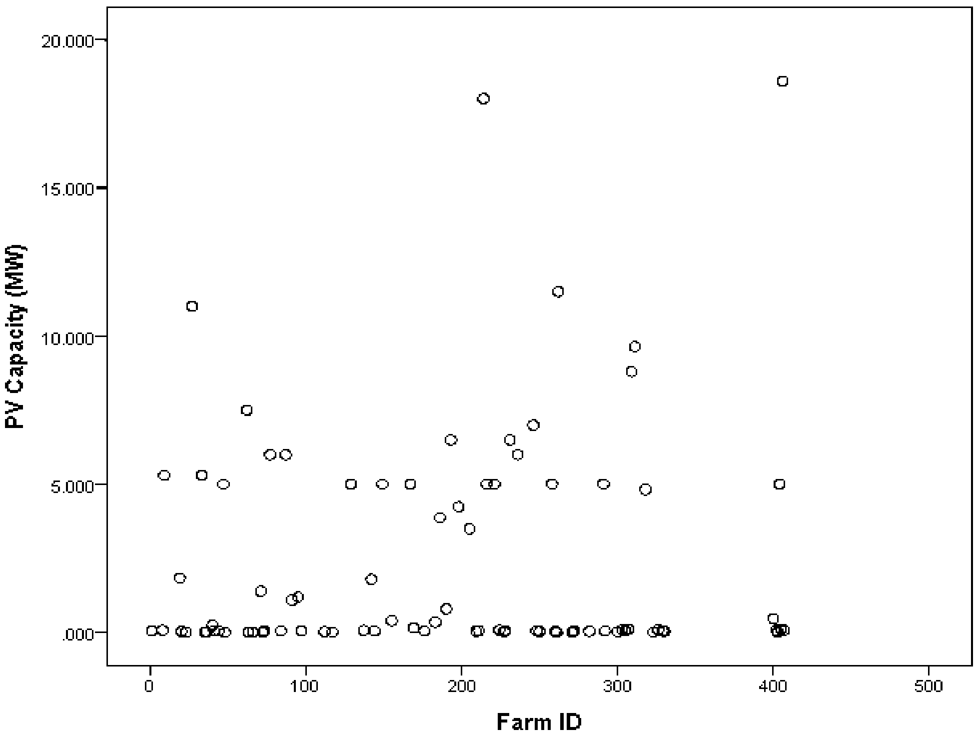

Figure 5-8: Scatter plot to show PV capacities (MW) of all of the respondent's farms.

Of those who own their array, and therefore have free access to the data from it, 6% did not know the amount of electricity generated, 8% said '*not applicable'* and 12% did not answer (n=50), which may suggest confusion or lack of knowledge amongst farmers about the electricity being produced.

There is an equally large range of PV array area sizes. The mean size of the area that the PV array covers, either roof space or field space, is 7.38ha with a standard deviation of 8.9ha (n=69) (see Figure 5-9). 11% of respondents did not know the PV area, 2% said '*not applicable'* and 12% did not answer (n=92). Of those who owned their arrays, 4% people did not know the subsidy scheme they were on, 2% answered '*not applicable'* and 2% did not answer (n=50).

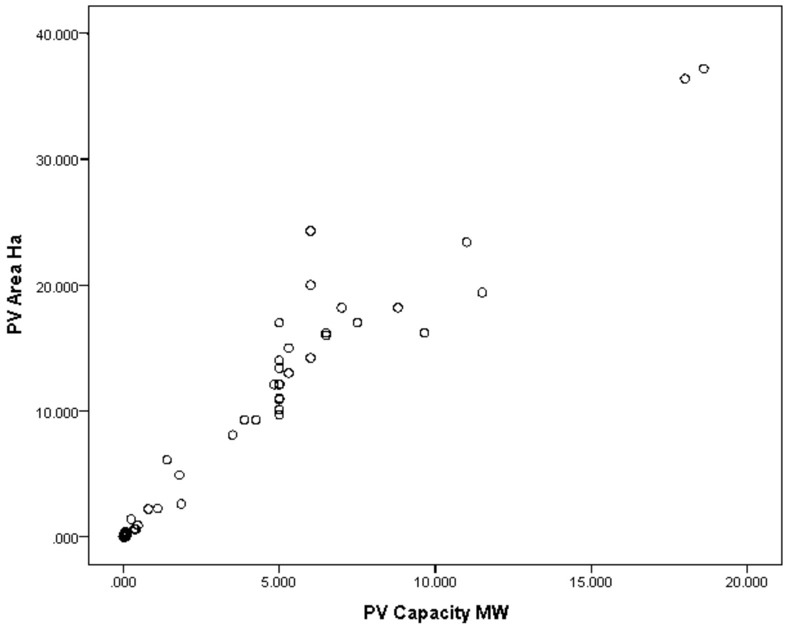

Figure 5-9: Scatter plot to show PV capacity (MW) of the farms plotted against the area of the PV array in ha.

The oldest array was connected to the grid in March 2010, just before the FiTs were introduced, and the most recent was November 2013 (n=78). The majority of the arrays are sited on the ground, but 7% of respondents have both a ground and a roof array (n=89) (see Figure 5-10).

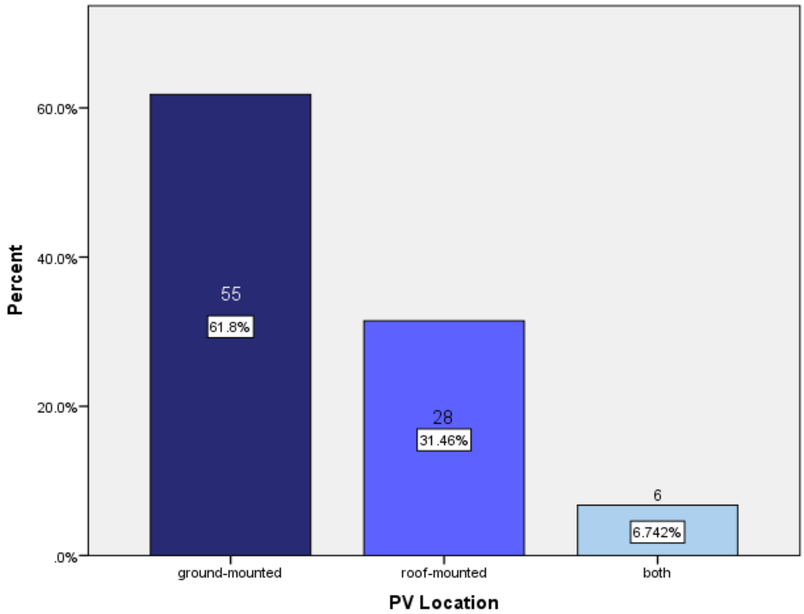

Figure 5-10: Graph to show the location of the respondents' PV arrays.

Only 54% of the PV arrays are owned by the farm owner, the rest are owned by external companies (see Figure 5-11). In return for the roof or land space used by these arrays, the majority of the farmers receive rent from the external companies. A small proportion of farmers receive a combination of reparations from external companies (n=92) (see section 7.6 for a further discussion on reparations).

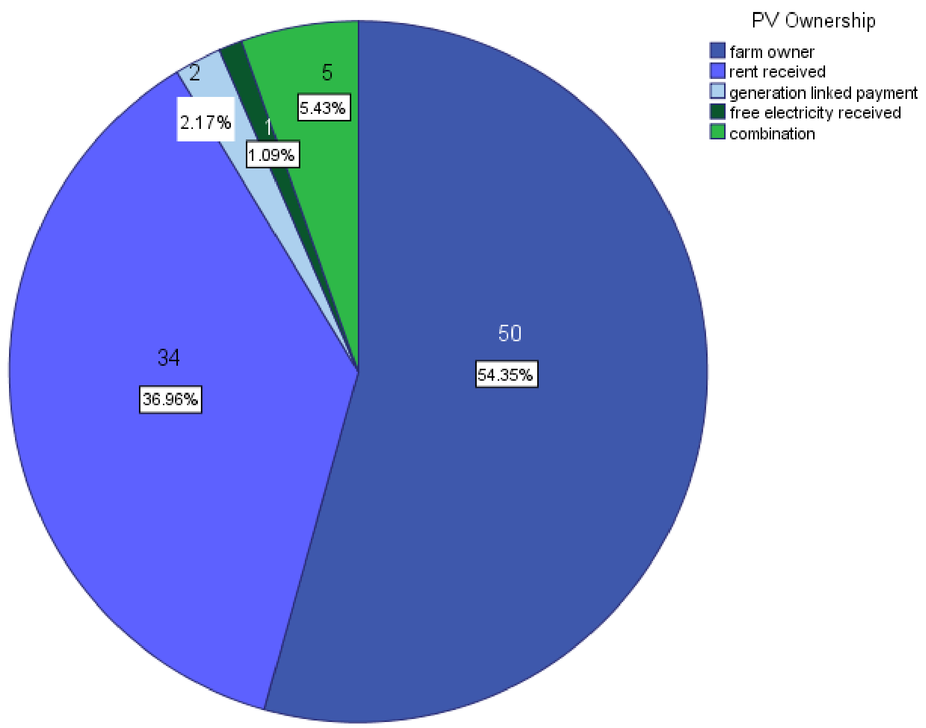

Figure 5-11: Pie chart to show breakdown of forms of PV array ownership.

16% of the PV arrays are not exporting electricity to the grid, so all the electricity produced by them is used onsite (n=81). Of those who own their arrays (n=50) 10% did not know the amount of electricity exported, and 2% did not answer, again showing a lack of knowledge by some farmers as to the electricity being produced. 64% of farmers are using the electricity produced by the array for household and agriculture uses, whilst 27% use the electricity for non-agricultural onsite businesses such as tourism, retail and offices (n=60).

40% of farmers are grazing animals at least part of the year under their ground-mounted panels, keeping dual use of the land. 5.5% of the farmers have planted the land under the array with wildflowers, and 3.5% of farmers now manage the land under and around their arrays as wildlife areas (n=55). Therefore in some cases the land is being actively managed to improve wildlife habitats and increase biodiversity. The other farmers are just maintaining grassland under their panels (47%), and 4% answered '*not applicable'*. However a high majority of farmers have not changed their behaviour in relation to their farming methods (92%, n=69), energy efficiency (60%, n=44) or carbon footprint (86%, n=61) since installing a PV array.

53% of the PV arrays cost at purchase between £50,001-£250,000 (n=61) (see Figure 5-12). Of those who own their arrays, 2% of respondents did not know this cost and 8% said '*not applicable'* (n=50). Of the 26 farmers who rent out their land or roof space to external companies and were willing to provide details, the mean rent value is £35,000 per annum, with a large range from £5,000 to £80,000, although it is unknown why rent values varied so much. Five of those farmers were willing to provide extra detail about the structure of their payments, with one receiving £850 per acre per year, two £1000 per acre per year, one £1200 per acre per year and another £1800 per acre per year. One farmer commented that they were not willing to disclose financial details and another had signed a non-disclosure agreement with their company and so were unable to. Of those who rent their arrays, 3% of people chose '*not applicable*' for rent, whilst 13% said '*not applicable*' and 16% did not answer, probably because of the sensitive nature of the question (n=42).

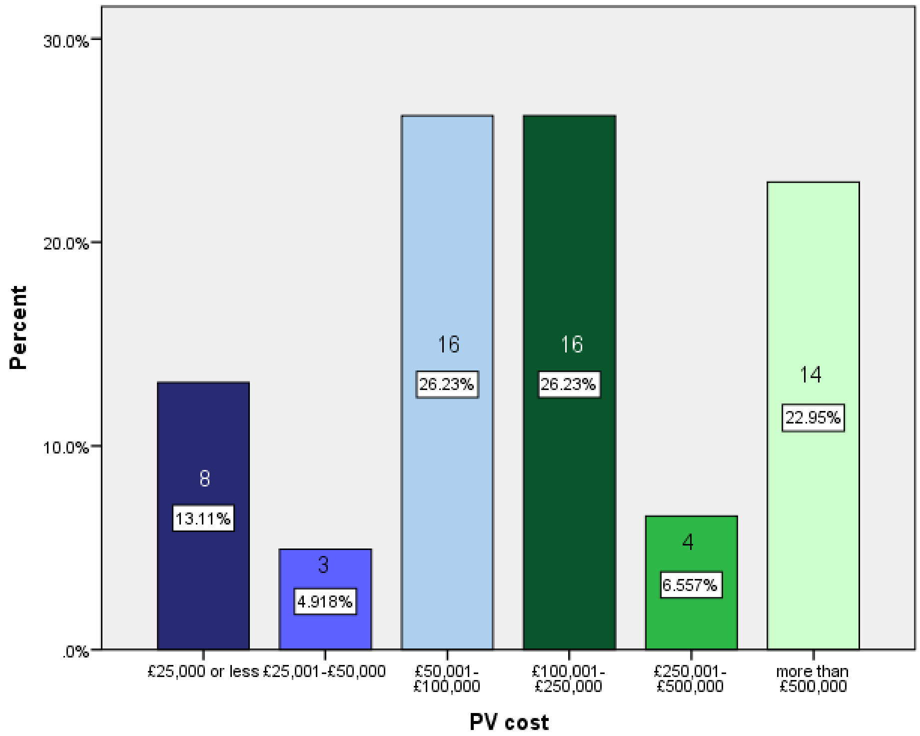

Figure 5-12: Graph to show grouped cost at purchase of respondent's PV arrays.

The mean price paid for exported electricity is £0.065 per KWh (n=2 5), ranging from £0.03 to £0.377. This is a good price - the export rate for solar panels installed after 1st August 2012 is £0.045 plus inflation. Of those who own their array, 18% did not know the price they were getting for exporting electricity, 20% answered '*not applicable*' and 14% did not answer (n=50). This question in particular was one which not many people answered, most likely because of a lack of knowledge. The price for exported electricity is not correlated with PV array capacity, (Spearman's rank correlation coefficient 0.269, p value 0.193).

Of those who own their arrays, 52% of farmers had a predicted ROI of 10% or more, however 6% did not know this figure, 10% answered '*not applicable'* and 16% did not answer (n=50). 48% estimated their current ROI at 10% or more, 18% did not know, 2% answered '*not applicable*' and 8% did not answer (n=50). There was a large disparity in knowledge between farmers for this question, with many not knowing and some farmers giving precise answers. Detailed answers included a current ROI of 14%, 20% and two farmers said 25%. 10% of farmers saw an increase from their predicted ROI after installation, whereas only 6% saw a decline (n=50). 9% is the average ROI given which farmers said would be a minimum threshold that would make installing PV worthwhile (n=42), answers ranged from 3% to 15%. See 5.3.1 for a further discussion of the relationships between this ROI value and farm size. Overall, it appears that farmer's are getting a significant ROI from their PV arrays, and also require a high ROI threshold for such investment. This confirms the results of Frazer (2013), who found that farmers felt renewable energy provided a better ROI than farming.

When asked by how much their electricity bills have been reduced by since installation of their PV array, 46% farmers estimated this reduction was by 26-50% (n=24) (see Figure 5-13). Of those who own their arrays, 44% did not know the answer to this question, 10% answered '*not applicable'* and 4% did not answer (n=50). Again this shows a lack of knowledge of detailed information about the electricity produced from the array.

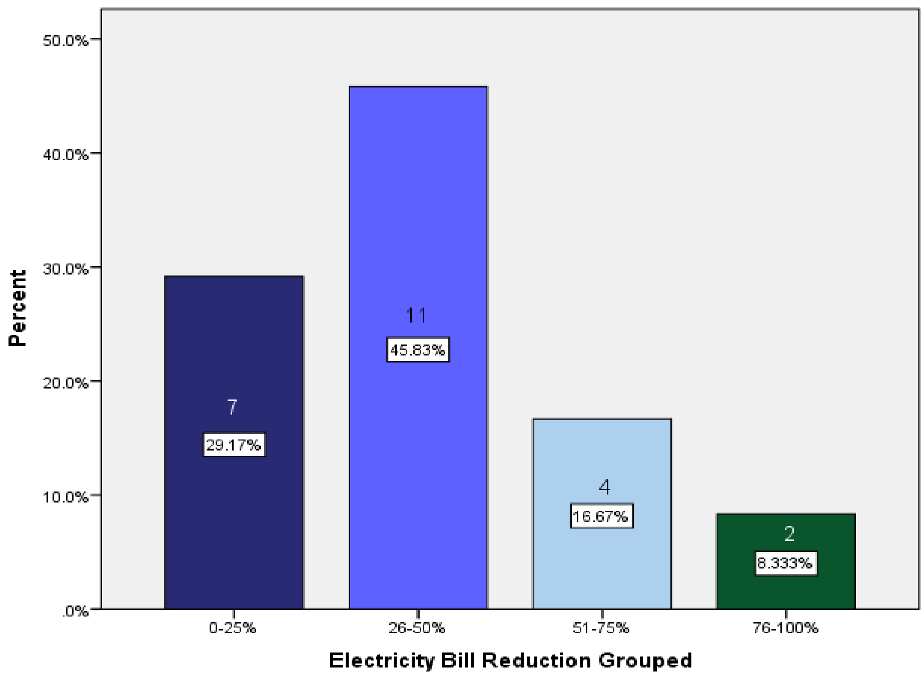

Figure 5-13: Graph to show the grouped percentage of electricity bill reduction experienced by the respondents after installing a PV array.

The highest mean Likert score for the likelihood of farmers installing further renewable technologies on their farms was 1.418 for wind power, with other means lower but similar in value. Overall, response to installing further renewables was very negative; however 41% of farmers did already have other renewables on their land. Of those who answered this question, 13% already have biomass, 9.8% have further PV, 7.6% wind turbines, 6.5% solar thermal, 3.3% anaerobic digestion and 1.1% have an air source heat pump. Despite relatively positive reports of good ROI, overall it appears that many farmers would not install a renewable technology again (see section 7.7 for a further discussion on this).

5.3 Exploring Relationships

As outlined previously, very few studies have been conducted on PV uptake on farms. Therefore relationships needed to be explored between all different aspects of the data. This was done by cross analysing each variable with other variables that might influence it, using different statistical tests depending on the type of data involved. The significant relationships are reported below.

In order to explore relationships between variables, correlations were calculated in order to determine the direction, strength and significance of relationships. If the data was normally distributed, as tested for using a KS test, then the parametric Pearson's correlation was used, if it was not normally distributed then the non-parametric Spearman's rank correlation coefficient was used. Preliminary analyses were performed to ensure no violation of the assumptions of linearity and homoscedasticity (Pallant, 2010).

5.3.1 Farm vs. PV Array Characteristics

The correlation between farm size and the lowest value ROI to make PV installation worthwhile was explored. When the data for farm size was tested the KS statistic was 0.295 with a p value of 0.000. The KS test for the data on lowest ROI gave a statistic of 0.162 and a p value of 0.007. Therefore

Spearman's rank correlation coefficient was used, which gave a value of 0.360 and a p value of 0.024. There was a weak positive correlation between the two variables, which was statistically significant. The coefficient of determination (how much variance the two variables share) was 13%. Larger farms are therefore more demanding on the ROI needed for projects to be undertaken, echoing the findings of Blackstock *et al.* (2010) that larger farms are more concerned with profit.

As tested for using either the Kruskal-Wallis, Chi-Square or Spearman's rank correlation coefficient tests, there is no significant relationship between PV capacity and farm location/farm size/farm type, or between PV location and farm type/farm size/farm location. Therefore farm characteristics as a whole are not related to PV array characteristics.

This section has explored the relationships within and between farm, farmer and PV array characteristics, in order to determine potential patterns for further exploration. All logical combinations of variables were tested against each other using the relevant non-parametric statistical tests, and statistically significant results were reported. The next section will describe the multivariate data analysis that was carried out on the Likert scale data.

5.4 Factor Analysis

In order to explore whether there are different groups within the data, factor analysis was carried out, followed by cluster analysis. The aim of this was to determine if a farmer segmentation model could be created, a methodology used by Garforth and Rehman (2006) and Fisher (2012).

As part of the postal survey, a series of 25 statements (see Appendix 2) were given and the respondents asked to give their response on a Likert scale of five points, from strongly disagree to strongly agree. These statements explored drivers of PV installation, barriers to PV installation, impacts of PV arrays and aspects of farmer behaviour. Factor analysis is a multivariate procedure which produces a smaller number of linear combinations of the original variables in a way that accounts for most of the variability in the pattern of correlations (Pallant, 2010). The responses to the 25 Likert scale statements could therefore be analysed to determine if a smaller number of factors explain the variability in these responses. Principal Component Analysis, the most common technique, was used for the factor extraction (Garforth and Rehman, 2006). See Appendix 3 for further detail on the factor analysis methodology.

The factor extraction led to a seven factor solution. To interpret the factor solution, the variables that have large 'loadings' on the same factor must be looked at (see Table 5-3). These are variables with scores above +-0.55 (Hair *et al.,* 1998). Each factor was named according to the variables present and the strength of their loading. Factor scores were saved as a new variable and later used for cluster analysis.

Factor	Factor Loading
Farmers who are motivated by environmental concerns.	
I installed solar PV because I thought it was a good way to reduce my business' carbon footprint.	0.812
I am concerned about the possible impact of climate change on my business.	0.787
I installed solar PV because I thought it would help reduce the impact of electricity price rises on my business.	0.699
I have gained confidence in reducing my business' carbon footprint since installing my PV array.	0.673

Farmers who are motivated by financial concerns.	
My farming/management decisions are based mainly on financial considerations.	0.852
The main aim of my farming/land management is to try and make as much profit as possible	0.790
I installed solar PV because I thought it was a good way to diversify my business.	0.654.
Farmers who found installing a PV array difficult.	
Choosing a company to supply and install my PV array was difficult.	0.770
Securing the finance needed for my PV array was difficult.	0.688
I found the planning process associated with my PV array difficult to negotiate.	0.679
Farmers who have experienced a positive financial impact from a PV array.	
The increased income from my PV array has allowed me to invest in my business.	0.809
The increased income from my PV array has made my business more financially secure.	0.770
I have had interest from other landowners/farmers since installing my PV array.	0.563

Farmers who found installing a PV array easy.	
Connecting my PV array to the grid was easy.	0.669
Installing my PV array was a challenge for me.	-0.665
Having the PV array installed was disruptive to my business.	-0.615
I was confident in my ability to have my PV array installed successfully.	0.586
Farmers who are influenced by external factors.	
Other people's opinions influenced me to install my PV array.	0.790
Other people's opinions are important to me when I make decisions about my business.	0.713
When planning my PV array I was worried about uncertainty with renewable energy policies.	0.704
Farmers who are engaged with their local community.	
I have had interest from local media since installing my PV array.	0.733
I am interested in being involved with community-owned renewable energy schemes.	0.664

Table 5-3: The 7 factors and associated statements from the factor analysis.

The seven factors are summarised in Table 5-4.

Farmers who are motivated by environmental concerns- this factor accounts for 10.417% of the total variance. Farmers with high scores for this factor installed a PV array in order to reduce their carbon footprint, are concerned about the impact of climate change and have gained confidence in reducing their carbon footprint since installing a PV array.

Farmers who are motivated by financial concerns- accounted for 10.072% of the variance. These farmers make business decisions based on financial drivers and installed a PV array in order to diversify their businesses.

Farmers who found installing a PV array difficult- accounted for 9.994% of the variance. These farmers identified the barriers to installing a PV array as choosing a suitable company, securing the finance needed and negotiating the planning process.

Farmers who have experienced a positive financial impact from a PV array- this factor accounts for 9.926% of the total variance. Their PV array has allowed these farmers to invest in their businesses and make them more financially secure. They have had interest from other farmers since installing their PV array.

Farmers who found installing a PV array easy- this accounted for 8.912% of the variance. These farmers found the process of installing a PV array easy and not disruptive to their business, and were confident the process would be completed successfully.

Farmers who are influenced by external factors- 8.279% of the variance. These farmers are heavily influenced by other people, and were so when choosing to install a PV array. They were also worried about uncertainty surrounding renewables.

Farmers who are engaged with their local community- 6.602% of the total variance is explained by this factor. These farmers have had local media

interest in their PV array, and may be interested in joining community-owned renewable energy schemes in the future.

Table 5-4: The seven factors produced by the factor analysis.

5.4.1 Summary

Factor analysis is a technique which forms the first part of creating a farmer segmentation model. It used the 25 Likert scale statements asked in the survey, based around a series of different themes relating respondent's experiences of installing a PV array. Factor analysis was used to determine if a smaller number of factors explain the variability in the responses to these statements. Initially nine factors were identified, but this was narrowed down to seven factors using further tests of the data. Altogether 61.530% of the variance in responses was explained by these seven factors, ranging from 10.417% for the first factor down to 6.602% for the seventh factor, showing that the factors are all roughly equal in their importance, however there is a portion of responses which are not defined by these seven factors.

5.5 Cluster Analysis

Cluster analysis is a data reduction tool that groups respondents into clusters according to similar characteristics. Factor analysis and cluster analysis are different techniques with different goals, they are the obverse of each other, and can therefore complement each other and enhance data analysis when used in succession (Gorman and Primavera, 1983). Factor analysis shows the level of correlation between the variables, and cluster analysis establishes the association between cases in relation to the variables. It is hoped that this will allow the segmentation of farmers into defined groups.

However, it is important to point out that both factor and cluster analysis are exploratory techniques, and the results can rely heavily upon the decisions made by the researcher during the process. They do not interpret the data in any way (Burns, 2009). The cluster analysis process is described in Appendix 4, and produced two distinct clusters, as shown in Table 5-5.

Cluster 1- Farmers who were financially motivated but challenged by the PV process. The first cluster accounts for 71% of the sample (n=38), and is characterized by farmers who found the process of installing a PV array difficult, and who were motivated to install an array by financial concerns. They are engaged with their local community and are influenced by external factors. These farmers were not driven to install a PV array by concern for the environment and don't feel they have benefited financially from the array. **Cluster 2- Farmers who were motivated by environmental concerns and found the process easy.** The second cluster accounts for 29% of the sample. It is characterized by farmers who found the process of installing a PV array easy, and who were driven to do so by environmental concerns rather than financial ones. They are not engaged with their local community. and are not influenced by external factors, nor do they feel they have benefited financially from their PV array.

Table 5-5: The two clusters produced by the cluster analysis.

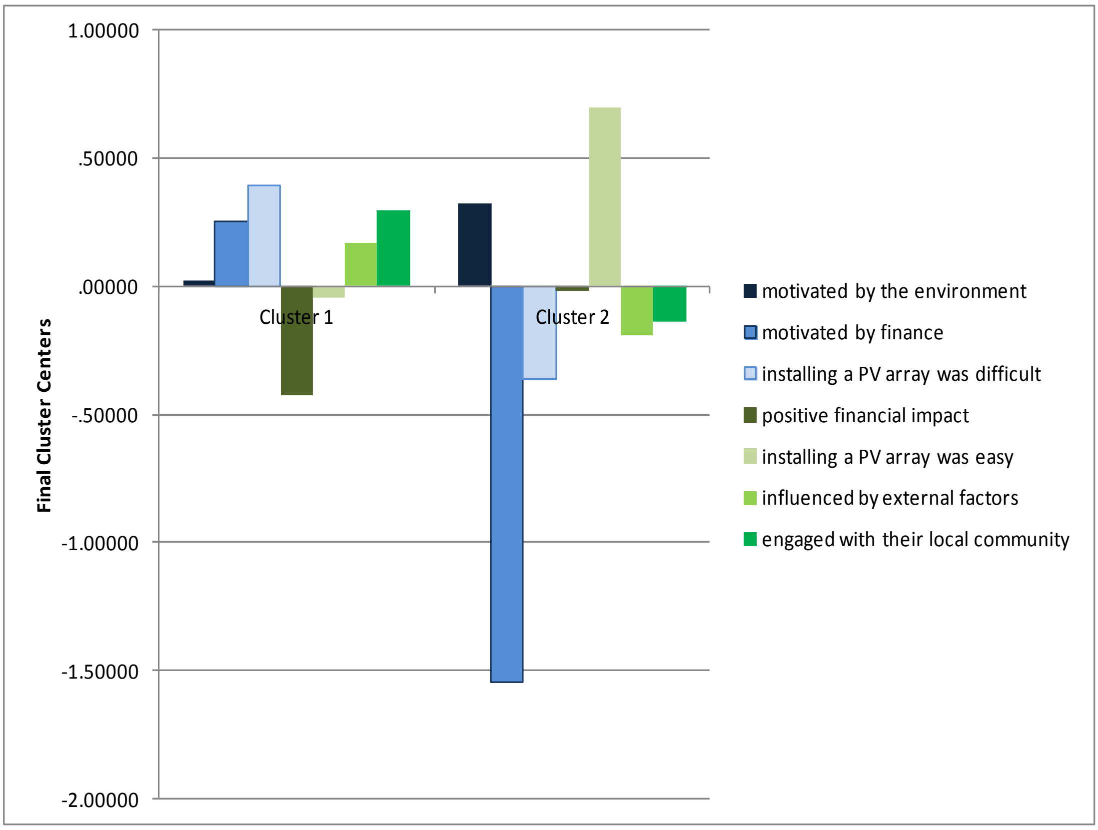

Figure 5-14: Graph to show cluster centres for each factor for cluster 1 and cluster 2.

The two clusters that were defined by the cluster analysis were explored further, by analysing other variables in the survey that were not included in the factor and cluster analysis, to see how these may differ between the clusters (Burns, 2009). Chi-square tests of independence were used for nominal variables and the Mann-Whitney U Test was used for ordinal and continuous variables. These included farmer, farm and PV array characteristics. There were no differences between age, education, farm location, farm type, farm size, farm ownership, date of installation and other variables between the two groups.

The only statistically significant relationship, tested using the Mann Whitney U Test, was between PV array capacity and the memberships of the clusters. The test static was 84 with a p value of 0.006. On closer inspection of the data, group 1 has higher PV capacities (mean 2.41300MW, SD 3.856275MW) than group 2 (mean 1.17142MW, SD 4.094040MW).

5.5.1 Summary

Cluster analysis is the second technique that will help to create a farmer segmentation model, and aims to group respondents into clusters according to similar characteristics. Hierarchical cluster analysis was run followed by non-hierarchical cluster analysis, identifying a two cluster solution. Cluster 1, farmers who were financially motivated but challenged by the PV process, accounted for the largest percentage of assigned respondents (71%), whilst cluster 2, farmers who were motivated by environmental concerns and found the process easy, only accounted for 29%.

The final technique to create a farmer segmentation model was to characterise these clusters, by analysing any significant patterns between the two. The only relationship found was related to PV capacities, with cluster 1 respondents having a larger mean PV capacity (~2.4MW) than cluster 2 (~1.2MW).

5.6 Summary

This chapter described and analysed the quantitative results from the postal survey of farmers who have PV arrays installed. A descriptive analysis of farmer characteristics was given, which went on to show that respondents had higher levels of education than would be expected. The description and subsequent analysis of farm characteristics showed that those with PV arrays were very likely to be privately owned farms and located in South West, and very unlikely to be in the North of the country. There were more poultry farms and less arable ones in the sample than would be expected, and fewer farms under 50ha and more farms larger than 50ha.The average PV array in the sample is 2.43MW in size. 54% are owned by the farmer, the others by PV companies. Most farmers were predicted, and are currently receiving, a ROI of 10% or more. 40% of farmers already have other renewables technologies on their farm, but overall were negative when asked if they would install any more.

Factor analysis was conducted, identifying seven factors that counted for 62% of the variability in the data. Cluster analysis was then run on the factor scores for each respondent, which led to the identification of two distinct clusters. These two clusters can be characterised by the size of the PV array the farmer has. Those in cluster 1 have smaller PV arrays and are more driven by environmental issues, whereas those in cluster 2 have larger PV arrays and are more driven by financial considerations.

The qualitative data will now be explored in order to corroborate these findings, and investigate in further depth key themes, before the significance of the findings is discussed in further detail.

Chapter 6. Qualitative Data Analysis

6.1 Introduction

This chapter describes the qualitative findings from the postal survey of farmers. The data was taken from the open-ended questions (question 23a, 23b and 23c - see Appendix 2), and also from the comments box at the end of the survey in which farmers could add extra detail or bring up new topics. 85% of the 92 farmers provided further comments for analysis. The open-ended questions provide a prompt for all of the respondents to comment on if they wish, whereas the open-ended comments box provides self selected comments in addition to their data. This may result in more negative comments and examples of problems than positive ones.

The codes used for data analysis were based around the key themes identified in the literature review: drivers, barriers, impacts and farmer behaviour. The data is presented by these key themes. The analysis was undertaken in NVivo software.

6.2 Drivers of PV Installation

The drivers of PV installation which were commented upon by the respondents included environmental drivers and financial drivers.

6.2.1 Environmental Drivers

In response to a question asking whether respondents had changed their farming methods to be more environmentally friendly since installing their PV array, 20% of respondents expressed the view that they were already farming in this way before they decided to have a PV array, for example:

> *'I already manage the land in an environmentally friendly way.'*

> *'Our farming practises and external auditing already encourage environmental best practice.'*

Overall, 84% of the 92 respondents were in the ELS scheme, 23% were in HLS and 6% were organic, whilst others were involved in other schemes such as LEAF (2%) and the WGS (2%) (see section 5.2.2). 10% of these farmers went into further detail of how they already farm in an environmentally conscious way, for example:

> *'We have reduced fertiliser use to zero and spray use is minimal.'*

> *We already farm in an environmentally minded way- a quarter of the farm grows SRC energy crop, 60 acres of wildflower meadows/field margins, 40 acres of new woodland over last 20 years.'*

It therefore appears that a large majority of the respondents had already begun a trend of environmental considerations, and installing PV was a continuation of this trend. One farmer outlined that:

> *'PV was part of our environmental strategy.'*

Of the 20% who elaborated on their existing environmental work, 67% had PV arrays under 1MW, supporting the findings of the cluster analysis (see section 5.5) which identified a cluster of farmers with smaller arrays that were motivated by environmental reasons.

An exception was noted for one farmer, who is moving back towards more resource-intensive agriculture, but did not explain why:

> *'Just converted from organic back to conventional.'*

6.2.2 Financial Drivers

Two farmers acknowledged their concern for the environment, but went into more detail about their motivations, citing financial concerns as the most important element, for example:

> *'It is more based on economics; we already take the environment into account.'*

Another farmer installed PV simply:

> *'Because it is cost effective'*

These were all farmers from very large farms (200ha+). This supports the findings presented in section 5.3.1 showing a positive correlation between farm size and lowest ROI needed for renewables projects. This corroborates the findings of Blackstock *et al.* (2010) who showed that larger farms are more concerned with profit than smaller farms are.

6.2.2.1 Energy Costs

Two farmers detailed specifically that energy costs were a large part of their decision to install PV, for example.

> *'…to manage our energy as environmentally as possible and also control our energy costs. Having our own energy systems…is our way of coping with the impending future energy costs and supply shortages.'*

Linked to this concern about energy price rises is the desire to become more independent as a business, therefore reducing the risks associated with large energy consumption, as commented upon by two other farmers:

> *'It is dual purpose we intend the farm to be an exporter of energy and as independent as possible.'*

Electricity prices were also cited as a key concern in a study of Scottish wind arrays on farms (Sutherland *et al.,* 2012). However those farmers that cited financial drivers are mainly made up of mixed and arable (potato) farms, perhaps because of the high energy usage need for livestock housing and potato cold stores.

6.3 Barriers to PV Installation

6.3.1 Policy

Government uncertainty over commitment to the FiTs and green energy subsidies in general (see section 3.1.1) was commented upon by two of the farmers. The rapid FiT rate degression, which was announced at the end of 2011, led to developers rushing to complete arrays which were in the planning process so that they could be connected in time to qualify for the higher rate FiTs. PV development companies were working long hours right up to the deadline to get arrays finished and connected. Some of the respondents were affected by this:

> *'The disturbance when the PV array was installed was dreadful, due to weather in November/December and the government deadline reduction'.*

For one of these farmers this had a dramatic effect on the size and scale of the planned PV array:

> *'We applied for planning for a 50kW PV array, but because of government uncertainty we were not able to get Western Power to install a 3 phase transformer in time for the FiTs. It was not viable for us due to high supply costs with lower FiTs, we thus cancelled and just installed 4 domestic supplies.'*

These kind of large-scale policy changes can reduce people's confidence in the government, especially at a time when PV technology is still reliant upon subsidies to make it competitive. Despite the bad experiences of these particular farmers, the average response to the statement 'when planning my PV array I was worried about uncertainty with renewable energy policies' was 3.31, only just above neither agree nor disagree. Therefore overall policy changes do not seem to have affected the respondents' confidence in PV technology.

6.3.2 Finance

Three of the respondents commented that the banks were not providing enough financial support for PV projects:

‘Banks have let down all landowners in not financing projects’.

However, despite some farmers feeling that the banks were not providing help, overall the respondents slightly disagreed with the statement ‘securing the finance needed for my PV array was difficult’ (mean response 2.3). This is in contrast to a survey by Farmers Weekly (2012), who found that a third of farmers found it difficult to get access to finance for renewables, but supports research on wind turbines by Sutherland *et al.* (2012) which showed farmers in Scotland felt the banks were being supportive.

6.3.3 Information

Another issue identified by four of the farmers is the extent of knowledge available to them, but not knowing which information is trustworthy. This includes the choice of PV development company, for example:

‘Too much information but of questionable veracity.’

Uncertainty over whether to trust PV development companies was also found in research on Scottish wind turbines by Sutherland *et al.* (2012). However overall the average answer to the statement ‘when planning my PV array there was plenty of information available to me’ was 3.54, slightly agree, and to ‘choosing a company to supply and install my PV array was difficult’ it was 2.8, slightly disagree. This is in contrast to the NFU Farm Energy Service (Farmers Weekly, 2012) which found access to information as the third most significant barrier for renewable energy by farmers.

6.3.4 Distribution Network Operators

Another significant barrier, that was not identified in the literature but has emerged from the survey, was a lack of cooperation from the distribution network operators, who own and operate the electricity distribution network. Farmers have had problems with communication and the length of time responses to queries took. They have also been held liable for the cost of any upgrading work which may need undertaking in order to connect the PV array to the grid. Five of the respondents elaborated on this, for example:

> *'The biggest problem has been with Western Power distribution; they have kept us waiting for 2 years for a grid connection and have demanded in excess of £1 million for upgrade work.'*

These experiences may not have been shared by all though, the average response to the statement 'connecting my PV array to the grid was easy' was 3.18, slightly agree. It did however have the largest standard deviation (SD) of the barrier statements, showing that there were a large variety of responses.

6.3.5 PV Development Companies

The average response to the statement 'choosing a company to supply and install my PV array was difficult' was 2.80, close to neither agree nor disagree. For the statement 'having the PV array installed was disruptive to my business' the average response was 2.29, slightly under disagree. Therefore overall respondents did not have a very negative experience choosing and dealing with PV companies. However four farmers did report having problems with their PV companies. This mainly involved the physical process of installation, and the disruption it caused to them and their farm, for example:

> *'The company which installed the PV system were very messy and after 9 months have still to tidy up the roadway to the site.'*

One farmer also had a problem with his company changing once the contract was underway:

> *'Problems when lease assigned to different company from the company we did original deal with.'*

6.3.6 Planning

Another barrier which was mentioned by two of the farmers was the planning process:

> *'Negotiating a further 7 acre site, but failed to get planning permission.'*

One of those farmers cited the planning process as a barrier, even when locals appear to be in support of the scheme:

> *'The planner did not want it on the house roof (it is a listed building) nor on the milking parlour roof, nor across the road in a field….we really tried, the village wants it but the conservation office doesn't'.*

The average response to the statement 'I found the planning process associated with my PV array difficult to negotiate' was 2.51, slightly disagree. However as by definition the respondents to the survey already have PV arrays, they will have successfully negotiated the planning process at least once. Therefore planning may be a significant barrier, and indeed it has been for some people when applying for a second array, but this may not be evident in this research. A Farmers Weekly (2012) survey found that planning permission was cited as the greatest perceived barrier to renewable energy by 50% of farmers who already have renewable technologies, and was also identified as a significant issue for farmers installing wind turbines in Scotland (Sutherland *et al.*, 2012).

6.3.7 Community Conflict

Conflict can also occur between the farmers and the local community, particularly amongst people whose properties are in close proximity to the PV array: three farmers commented to this effect, such as:

> *'Objection from mainly retired people, NIMBY, only six houses can see the site from the ground floor but 70 people objected, some from three miles away.'*

Respondents seemed particularly frustrated by objection from people whose houses were not adjacent to the array, a finding also mirrored by research on wind turbines in Scotland (Sutherland *et al.*, 2012). Overall the average response to the statement 'When planning my PV array I was worried about local opposition to it' was 3.05, neither agree nor disagree. A survey by Farmers Weekly (2013b) found opposition from family/community one of the top five barriers to on-farm renewable energy generation, however it was not brought up as a major issue in this study.

6.3.8 Overall Process

Three of the respondents seemed very positive about their overall PV experience, such as:

> *'We are pretty passionate about PV.'*

Whilst five people were more negative about their experiences, for example:

> *'It's not as easy to achieve as people make out and takes a long time.'*

With four finding disadvantages they had not anticipated:

> *'Electricity produced during summer but needed during winter.'*

The average response to the statement 'Installing my PV array was a challenge for me' was 2.68, slightly disagree. Therefore overall most people did not find the experience too challenging.

6.4 Impacts of PV Arrays

There were three main areas of impacts that respondents elaborated on, these included financial, environmental and community impacts.

6.4.1 Financial Impacts

Farmers gave a lot of detail about the ways in which the PV array has improved the financial situation of their farm, with 15% of people commenting on this. One farmer talked about the PV array subsidising their farming practises:

> *'Takes the financial pressure off land production. Harnessing the sun is a win-win situation for a sheep farmer. Not only can I harvest the sun as a crop or income, but I can still produce meat from the lambs and my roof system supplies my cold room, saving energy, which is a source that will not run out!'*

Seven farmers reported that their businesses are now more stable, due to both diversifying enterprises and through an increase in income. This is being invested back into the farming business:

> *'In the future with the business on a more stable financial footing, we can consider projects to improve the farm.'*

> *'The income I receive has allowed me to invest in the farm, so that in the future I can run a diverse business, not have a business run me.'*

These farmers have nothing in common with each other (PV capacity, education level, farm type, farm size or PV ownership). These testimonies agree with the statistical data. The average response to the statement 'the increased income from my PV array has made the business more financially secure' was 3.83, agree, and for 'the increased income from my PV array has allowed me to invest in my business' it was 3.49, slightly agree.

Other farmers went into more detail about exactly how the extra money has helped:

> *'It has also enabled me to give the buildings a makeover.'*

> *'Survival of family owned farm. Prevented the sale of the farm.'*

Two others were using the money directly for personal financial planning:

> *'The money is sufficient for pension needs for the next 25 years.'*

Two farmers have even started up their own PV development companies as a result:

> *'Starting a business in PV as a result, the purpose of the PV is to add substantial collateral to the business for future projects.'*

One farmer brings up the issue of the impact that the lifespan of the PV array will have on the overall investment:

> *'Possibly the bigger issue or threat to ROI will be how long the equipment lasts particularly the inverters.'*

And two other farmers point out that they are not able and/or willing to discuss financial arrangements with outside parties:

> *'NDA in effect for rent price.'*

It was expected that the majority of respondents would not want to reveal details of financial arrangements, and most simply chose not to answer the associated questions (see section 5.2.3).

6.4.2 Environmental Impacts

Another impact which four farmers expanded upon is the impact the PV array has had on the farm environment, mainly because of the switch from intensive to extensive land use:

> *'The solar farm has reduced fertiliser use, less use of tractors and machinery'*

This is a potential benefit of PV arrays which has been highlighted by RSPB (2011). Five other farms explain that alongside more extensive use of the land, they have also actively managed the land to benefit wildlife and biodiversity, or are intending to:

> *'Ground around solar is being made into a wildlife habitat'*

Overall 9% of farmers who have ground-mounted panels are using the land under their array for wildflowers or wildlife areas (see section 5.2.3). Two others have highlighted the minimal visual impact that their arrays have on the local area:

> *'It is virtually out of sight…I've not seen any glare during the summer so hopefully all ok.'*

Therefore the environmental impacts reported have been positive, both indirect from changes in land use to direct and deliberate encouragement of biodiversity.

6.4.3 Community Impacts

There was little mention from the respondents about any impacts on the community their PV array might have had, other than opposition from individual locals as mentioned above. However one farmer did mention that he is using his PV array to educate others in the community:

> *'Educational use due to 50 school visits per year.'*

6.5 Farmer Behaviour

Farmers were asked whether their behaviour had changed since installing their PV array, based on energy efficiency and carbon footprints, and asked to explain these changes.

6.5.1 Energy Efficiency

When asked about energy efficiency, and whether they are more careful since installing their PV array, 9% of respondents expressed that they are not necessarily trying to use less electricity overall, but trying to use less electricity when the PV panels are not generating i.e. during darkness hours. This is more 'efficient' as it displaces external energy use and reduces the amount exported to the grid:

> *'Using electric in the day for maximum use of the electric generated by the PV system.'*

All of these farmers had PV array capacities less than 0.09MW in size and all but one owned their array (there was no other connection, such as between age, education levels, farm type, farm size). It may be that those who own their arrays recognize that they would benefit more from using their free electricity to replace buying in electricity at a high price rather than exporting it, and for small arrays the electricity produced is small enough to be able to achieve this on site-usage. This change in energy usage has not been observed before, in relation to renewable energy or specifically PV.

11% of farmers elaborated upon an increase in energy efficiency as a direct result of the process of installing their PV array:

> *''Whole process increases your awareness of electricity efficiency and cost and hence overall we have had a much greater focus on this'*

These farmers however did not have anything in common (education levels, farm type, farm size, PV ownership, PV capacity). This change in behaviour was one of the rationales behind the introduction of subsidies for small-scale renewables (Ofgem, 2009) (see section 7.7 for more detail).

Some farmers state that they were already engaged in energy efficiency before they chose to install a PV array:

> *'Already engaged in environmentally friendly farming and energy efficiency and carbon footprint.'*

Three farmers felt that their increased energy efficiency was due to high electricity prices rather than their PV array:

> *'Energy efficiency due to increase in prices'*

It was interesting that one farmer who owned their array reported being:

> *'Possibly less energy efficient'*

This farmer doesn't know how much electricity his array exports, and it may be that at 0.05MW he does not have an export meter. Therefore he has little incentive to save energy. This may be a recurring problem for those with small scale arrays.

Overall 60% of respondents answered that they have not changed their energy efficiency habits since installing a PV array (see section 5.2.3), and two commented to this effect:

> *'Energy practises remain the same…The PV has no impacts on other decisions'*

Irrespective of whether they own the PV array, many respondents feel the process of installing their PV array has not altered the level of importance they give to energy efficiency.

6.5.2 Carbon Footprints

Farmers were also asked an open question as to whether they have actively reduced their carbon footprint in other ways since installing a PV array. Although some have reduced their carbon footprint, for four farmers it appears to be as part of an on-going plan to become more sustainable rather than a change in behaviour caused by the PV array itself:

> *'Supported by solar thermal is just rest of the picture to manage our energy as environmentally as possible and also control our energy costs.'*

These four farmers had no common farm type, farm size, education level, PV capacity, or PV ownership.

One farmer acknowledged that their carbon footprint may have reduced, but only as a by-product of reducing costs through more efficient resource use:

> *'Looking to reduce costs but not necessarily carbon footprint.'*

Two farmers felt that they are more aware of their carbon footprint but have not necessarily undertaken any further actions to reduce it. Overall 86% people have not reduced their carbon footprint since installing the array (see section 5.2.3).

> *'More aware of carbon footprint but not changed yet.'*

Two farmers simply acknowledged that the PV array reduces their carbon footprint.

> *'The solar farm is allowing me to farm in a way that improves my carbon footprint.'*

One farmer was particularly negative about carbon footprinting as a principle:

> *'Carbon footprinting- life is too short.'*

And a further questioned the link between PV arrays and carbon reduction:

> *'Carbon footprints and PV are unrelated in my eyes.'*

6.5.3 Future Renewable Arrays

Many farmers already had more than one PV array, one farmer even had seven separate arrays. The evidence from the qualitative data shows that seven farmers would consider further renewables, some more PV arrays and others a different technology:

> *'Considering a small wind turbine, roof mounted panels, independent borehole, AD.'*

Two farmers have tried installing wind power but have not been successful:

> *'Had planning for wind turned down.'*

However the quantitative data shows most people are negative about installing further renewables. This contrasts with a survey by CCgroup (2013) and Frazer (2013) who found that farmers who had renewables were very likely to install further renewable technologies. This may be because 41% of respondents (see section 5.2.3) already have another renewable technology, and have not the desire or opportunity to have more.

6.6 Summary

This chapter has analysed the varied qualitative data, in the form of answers to open questions and additional comments, that the postal survey produced. It showed that for 20% of farmers PV was a continuation of a trend in more environmentally aware behaviour. Those with very large farms (200ha+), were driven by financial reasons, including rising energy costs. They were also found to be predominantly mixed and potato farms, because of their high energy usage.

There were some bad experiences with the distribution network operators, something that was not identified in the literature. There were also a few instances of problems with the PV companies as well. Access to finance, access to information, planning, community conflict and renewable energy policy were not elaborated upon as major concerns for most people. Overall, there were mixed feelings about how easy the whole process was.

15% of the respondents detailed how the extra income from their PV array is subsidising their farming and is allowing further investment into their business. There is evidence of the money being used for pension planning and for further entrepreneurial activities. The environmental impacts were shown to be of two different sorts, indirect and direct. The indirect impacts come from converting the land (with respect to ground-mounted arrays) from intensive to extensive use, with many farmers highlighting their reduction in chemical and machinery use. Direct impacts are the result of 9% of farmers actively managing the land for wildlife and biodiversity.

A very interesting outcome of the question on energy efficiency changes, is that 9% of respondents actively manage their energy use as to use more during daylight hours when the PV array is active, behaviour which has not been documented before. 11% of farmers reported an increase in energy efficiency behaviour since installing their PV array, some because of concern over energy prices. However the survey showed that 60% of respondents have not changed their energy efficiency behaviour. Any reduction in carbon footprint appears to be part of an on-going environmental plan, rather than a direct reaction to installing PV. The qualitative data also showed that some respondents are considering installing further renewables, and that some have tried and been unable to. The significance of these findings, and where more work is needed, will be considered further in the next chapter.

Chapter 7. Discussion

7.1 Introduction

This chapter will begin with a review of the data collection methods and will discuss the farmer segmentation model created, before presenting the rest of the discussion by the major themes of drivers, barriers, impacts and behaviour changes associated with PV arrays. This is done in order to logically analyse the experiences of farmers with PV arrays through from initial motivations to post-installation impacts.

7.2 Methodological Considerations

Overall using a survey as the data collection method for both quantitative and qualitative data allowed the broad range of data required for this research to be collected. The high response rate of 27% (see section 4.4.4) showed that many people engaged with the topic and were keen to discuss it: '*We are pretty passionate about PV'*, with 85% of the 92 respondents commenting further on particular areas of importance to them. Successful piloting of the survey and inclusion of a clear explanation of the purpose of the research will have encouraged this positive response.

Sending the survey by post allowed the targeting of those who, it was anticipated, had installed a PV array on their farm. However it did also result in many people not opening and/or ignoring the survey, perhaps 50% of those who were called after the deadline had no knowledge of the survey. It was also established from these calls that around 10% of the sample did not complete the installation of their PV array due to refusal of planning permission or had never expressed interest in solar power on their farm. A further problem experienced with using post as a survey medium was that even though the completion date was clearly given on the cover letter, three completed responses were returned up to eight weeks after this date. On the whole, the combination of quantitative and qualitative data allowed the triangulation of important findings and was an effective research approach.

The data collected was as anticipated and of good quality, and although some of the respondents chose not to answer some of the more sensitive commercial questions, this was anticipated in the design stage. What was interesting was that the qualitative data was quite detailed, and provided a range of topics for analysis.

High confidence is placed in the results of the statistical tests, as the p value has to be less than 0.05, giving a maximum 5% threshold of the results occurring by chance. However the farmer segmentation model discussed below was the result of two statistical processes which can be subjective: factor analysis and cluster analysis. In order to reduce this subjectivity as much as possible, each required decision was made after careful consideration of the literature (Hair *et al.*, 1998) and both hierarchical and non-hierarchical cluster analysis was undertaken.

7.3 Farmer Segmentation Model

The farmer segmentation model (see Figure 5-14) clearly demonstrates a division of farmers into two separate clusters. Cluster 1 is made up of farmers who were **financially motivated but challenged by the PV process**. Just over two thirds of the assigned farmers were in this cluster, and were driven to install their PV array by financial gain, and not by concern for the environment (this relates to the attitude section of the conceptual model, Figure 3-4). They found the overall process reasonably difficult. This difficulty was centered around choosing a company to install their array (which relates to the perceived behavioural control section of the conceptual model), securing the finance needed for the project and negotiating the planning process (both external influences). Cluster 1 farmers are also influenced by external factors, such as incorporating other people's opinions into their business decisions (part of the subjective norm), and are influenced by government renewable policies. These farmers have some engagement with their local community, due to interest in their PV arrays from local media and their willingness to be involved with community-owned renewable energy schemes in the future. They have not had interest from local landowners though, and do not feel that their arrays have had a positive financial impact on their business.

Cluster 2 is made up of farmers who were **motivated by environmental concerns and found the PV process easy**. These farmers were driven to install their PV array by environmental concerns and not by financial gain. They did not find the process difficult, are not influenced by external factors and are not engaged with their local community. They responded slightly negatively to questions on how their PV array benefitted them financially. Profiling of these clusters found that cluster 1 farmers have higher PV array capacities than those in cluster 2. The significance of this will be discussed in subsequent sections. There is an element of cause and effect here- those who are environmentally driven will often opt for smaller arrays as economies of scale are not as important for them, and therefore the process is easier due to less strict planning rules and practicalities, although due to the cost they are probably less likely to hire consultants to help them with the whole process.

The farmer segmentation model has helped to address research questions 2 and 4 (see section 3.12). Segmentation models are a useful tool for developing policy which is tailored to different sub-sections of groups of interest, increasing the likelihood that policy interventions will be successful and as predicted (Garforth and Rehman, 2006). They are based on behaviour theory (such as Ajzen's TPB (1991)) which states that different people have different attitudes, values, barriers and motivations and will therefore respond to different policy interventions (Collier, 2010). Defra has developed such segmentation models for the public, farmers and fishermen. Farmers are already subject to a range of policy mechanisms designed to influence behaviour such as capital incentives, market prices and advice and information, and traditionally policy has been tailored according to farm type. As farmers often have little external strategic input into their businesses, their individual opinions have a large influence over how they are run (Collier, 2010). In their farmer segmentation model, Defra identified five farmer types: custodians, lifestyle choice, pragmatists, modern family business and challenged enterprises (Pike, 2008). Of these, 'modern family business' matches best with cluster 1, as they value financial planning, whereas 'pragmatists' match best with cluster 2, who favour a balanced approach and have an emotional connection with farming. The farmer segmentation model developed in this study can therefore be used to inform renewable energy policy to target other farmers and landowners.

It is important to consider the limitations of this technique and the subsequent model. Only 38 of the 92 respondents were assigned clusters, as if one or more answers were missing for any of the 25 Likert statements then the analysis could not be run with that respondent. Therefore although these two clusters have strong differences, it is unknown whether the other respondents would fit into these categories or not. The farmer segmentation model will be further contextualised in the sections below, bearing in mind this limitation.

7.4 Drivers and Attitude

One of the research questions of this study was to ascertain if there are any common characteristics between farms which have PV arrays, and the farmers which install them. This in turn may influence the motivations behind installing a PV array. These drivers relate to the attitude section of the conceptual model (see Figure 3-4), and also link to the internal influences.

As demonstrated in the conceptual model, farmer attitude is thought to be affected by factors including age and education (Edwards-Jones, 2006). Patterns in the age groups of the respondents could not be determined due to the incompatibility of the collected age categories compared to the national data, which was an oversight that was made during survey development. What was found to be significant was that farmers with PV arrays had a higher level of education that the population as a whole (Table 5-1). This finding is also supported by the work of Sheikh *et al.* (2003) who found farmer education levels have a positive effect on the uptake of new technologies, and Vanslembrouck *et al.* (2002) who found that better educated farmers were more positive about undertaking AES. It also corroborates a DECC (2012b) study, which found higher rates of domestic PV arrays in areas of low educational deprivation.

One possible reason for this pattern is that farmers with a higher level of education are more confident in undertaking long-term capital projects on their farms. Obtaining finance or agreeing rental agreements with PV companies requires negotiation skills, the ability to understand financial calculations and a level of project management ability. Another reason may be because farmers with a higher level of education have a more positive attitude towards renewable energy in general. They may have studied sustainable energy as part of a degree course or are more concerned about national and global energy issues. Further exploration of this trend is needed, but it may be that greater investment in, and easier access to, renewable energy courses would allow a greater range of farmers to consider PV.

The cluster analysis clearly shows the presence of two main drivers of PV installation, financial drivers for cluster 1 and environmental drivers for cluster 2. The qualitative data also shows this, with 20% of farmers explaining that installing PV was a continuation of an environmental aim. The majority of these were farmers with smaller PV arrays, matching the profile of cluster 2. The prevalence of non-financial motivations amongst farmers has been noted by Garforth and Rehman (2006). The qualitative data also provided more detail on the financial drivers, which for some farmers was linked to an increase in energy costs. Furthermore, it was apparent from the qualitative data that for some farmers there was not one clear driver, they took into account both environmental and financial drivers. It was this detail which was lacking in the cluster analysis, for reasons outlined above. The fact that drivers are not mutually exclusive has also been found by other studies into renewable energy (CC Group, 2013) and AES (Wilson and Hart, 2000).

The data also showed a pattern not identified by the cluster analysis, with a positive correlation between farm size and the lowest ROI needed to make a PV installation worthwhile (section 5.3.1). Although this correlation is relatively weak, this is also supported by the qualitative data, and confirms research by Blackstock *et al.* (2010) which showed that larger farms are more concerned with profit and competitive advantages.

7.5 Barriers

One of the objectives of this research project was to examine the barriers to further PV implementation in the agricultural sector. It is important to understand the barriers experienced by farmers, in order to target policy changes designed to encourage PV take-up. It was theorised by Mendonça (2009) that barriers to renewable energy would fit into four categories: financial and market impediments, political and regulatory impediments, aesthetic and environmental impediments and cultural and behavioural impediments. This study has identified barriers in each of these categories.

The first barrier theme, financial and market impediments, includes the problem of access to finance. Farmers that were in cluster 1 of the farmer segmentation model scored highly on the factor *'Farmers who found installing a PV array difficult*', including strong responses to the statement '*Securing the finance needed was difficult*'. Three farmers also mentioned in the qualitative data that they were unable to get funding from the banks. However, those in cluster 2 did not identify finance as an issue and overall it appears not to be a widespread problem. Ultimately the respondents were all still able to finance their arrays. These results are in line with a survey by

Farmers Weekly (2012) who found that a third of farmers found it difficult to get access to finance for renewables.

Access to finance can be more complicated for those who rent their farms rather than own them. This research has shown statistically that farmers with PV arrays are more likely to own their farms than those in the wider agricultural population (Table 5-2). If finance can be secured against property or land then banks view this as low-risk and the process can be quite straightforward. For tenants this is much more problematic and security of tenure is a major factor. (It is important to note that those with AHA tenancies (see section 3.1.2) often have much more security and rights of succession compared to those with FBT tenancies). If the array is small enough that all the electricity is going to be used onsite then it can be argued that it is still for agricultural use, as most tenancies exclude non-agricultural use (Farmers Weekly, 2014). The landlord may demand a share of the rent or FiTs, or may even take land back from the tenant to develop it themselves. In this case, if non-agricultural use is established, the tenant is entitled to compensation of six years' rent, but if the land is also grazed this provides further complications (Farmers Weekly, 2014). There are no guidelines on this issue and tenants must therefore be careful to ensure the process of negotiation is well documented. DECC (2014b) have identified tenant finance as a problem and are exploring novel financing ideas to help address this.

Another financial and market barrier which was explored was that of the choice and reputation of PV suppliers. As the conceptual diagram shows, the quality of information can affect the perceived behavioural control of the farmer. Overall, respondents were neutral about the experience of choosing and dealing with PV companies, however the qualitative data showed there were some specific examples of problems (section 6.3.5). In contrast to this the NFU Farm Energy Service (Farmers Weekly, 2012**)** found access to information as the third most significant barrier for renewable energy by farmers.

A similar barrier is dealing with the electricity distribution network operators in order to connect the PV array to the grid, a problem identified by Sutherland *et al.* (2012). Problems included length of time it took for adequate communication, general frustration over the whole process and being liable for the cost of grid upgrade work (section 6.3.4). There were some very negative responses, however overall opinion was that connecting to the grid was easy. This has been picked up on by DECC, who have laid out plans for further engagement with DNOs and who are working with Ofgem to introduce industry penalisation for poor performance (DECC, 2014b).

There are two main political and regulatory barriers to PV deployment: the planning system and renewable energy subsidies. Gaining planning permission is also tied up with cultural and aesthetic issues, as it is often visual impact and objection on principle that cause people to object to PV development. Issues with negotiating the planning system formed part of the factor '*Farmers who found installing a PV array difficult*', which was a strong element of cluster 1. This is most likely because cluster 1 farmers had larger capacity arrays, making them larger in size and therefore planning permission harder to obtain. It is suggested that farmers who have roof arrays as compared to field arrays will have very different experiences of the planning system, which may explain why a Farmers Weekly (2012) survey found that planning permission was cited as the greatest perceived barrier to renewable energy by only half of farmers. Guidance on the planning process for renewable energy is given by DCLG (2013) and (2014), and outlines the importance of the views of local communities. By definition the respondents to the survey already have PV arrays, so they will have successfully negotiated the planning process at least once.

This research suggests that more support is needed in the planning process for farmers who are installing large ground-mounted arrays. However Part 2 of the UK Solar PV Strategy (DECC, 2014b) and the on-going DECC consultation (DECC, 2014a) outline plans to disincentivise large scale ground arrays, and to encourage small and medium scale roof arrays instead. To help achieve this aim, DECC are planning to consult with DCLG on extending the permitted development rights in England for building-mounted PV, possibly to include all arrays up to 1 MW (the current cut off point is 50kW and data shows a marked fall in deployment above this point). Original targets for PV deployment in Britain were 20GW by 2020 (DECC, 2013) but this has been revised down to 10-12GW (DECC, 2014b). It therefore seems unlikely that farmers wanting to install large-scale renewables will see any increase in government support, and may well see significantly less.

One barrier which is of particular interest is the lack of confidence caused by policy changes since the introduction of the FiTs, which has been widely reported in the media (EREC, 2013), and many have assumed that this is having a knock-on effect for prospective installers. This can be said for those farmers in cluster 1, who are influenced by external factors, one of which is uncertainty over renewable energy policies. Cluster 2 does not appear to be affected by this. The qualitative evidence goes into much more detail about the ways in which policy changes have affected the respondents. The rapid FiT rate degression announced at the end of 2011 led to inconvenience for some who had to rush through their arrays, and led others to reduce the size of their array. To have such a dramatic change in subsidy that planned installation becomes unprofitable may result in damage to the industry at a time when rapid changes in production and installation costs, combined with rising electricity prices, are bringing it closer to grid parity. However the overall response was that farmers did not find uncertainty with subsidies a problem. This is a positive sign in light of further policy consultations (DECC, 2014b), that are feared to be causing further damage to the industry.

One of the potential cultural and behavioural barriers identified in this research is that of community conflict. In the conceptual model (see Figure 3-4), communities can impact upon the subjective norm. The qualitative data provides examples where members of the local community objected to the plans even though there would be no visual impact from their houses, and the farmers found this very frustrating. However overall farmers in this survey appeared to be ambivalent towards this issue (section 6.3.6), in contrast to Farmers Weekly (2013) who found it to be one of the top five barriers to renewable deployment. Therefore the subjective norm does not seem to play a large role in behaviour when it comes to PV arrays, despite the fact that community engagement is one of the Solar Trade Associations 10 commitments (DECC, 2014b). As community engagement can increase the chances of planning permission being granted, it may be that farmers need to attach greater importance to the views of the local community, and should be encouraged to do so by PV developers.

This thesis has shown throughout that farmers' experiences of installing a PV are not homogenous, and some identify particular barriers whilst others do not. These barriers represent the external influences as identified in the conceptual diagram. It is also essential to remember that these barriers were not big enough to stop these farmers from installing an array, and some even have more than one array. It would be useful to try and identify farmers who had shown interest in PV arrays but have not actually installed them in order to examine if they perceive the barriers to be any different, but this is outside the scope of this study.

7.6 Impacts

One of the objectives of this research was to begin to assess some of the impacts that solar arrays may have had on farmers, the farm environment and the farm as a business. As the majority of solar arrays have only been operating since the introduction of FiTs in 2010, little academic work has been done on the impact of solar arrays, especially in the context of the UK. The possible impacts identified in the literature review include financial, environmental and community ones, which may vary depending on whether the arrays are ground-mounted or roof-mounted. It has been claimed that renewable energy is a win-win scenario for farmers (Wolfe, 2006) but the evidence base is too small to make such generalisations.

With increasing popularity and financial support, AES have pervaded farming in recent years, especially in the south west of Britain. This focus on agricultural sustainability has led to an increased pressure to use the land more extensively, and allowing dual use of land for solar arrays and wildlife makes this a viable model. This research has shown that 40% of farmers are grazing the land under their panels with livestock (of those who have ground-mounted arrays), whilst 47% are just maintaining grassland underneath. If the land was arable beforehand, then this will reduce the impact of the farming operations due to a reduction in chemicals and land disturbance. These arrays can cover a large areas, the largest in this study was 37ha. In addition to this, 9% of farmers are actively managing the land under their panels with the aim of improving wildlife habitats and increasing biodiversity. An initial study indicates that the use of wildflower mixes under solar arrays has a positive impact on biodiversity (Parker and McQueen, 2013). Although only an indication, the evidence would suggest that the environmental impacts are positive. However further work is needed in order to explore this, as well as other postulated benefits such as improved soil carbon storage. It is also worth considering that taking land out of agricultural production is opposed by many on principal, an argument which has long been debated with ‘green’ biofuel crops replacing food crops in many areas (Tilman *et al.,* 2009).

Another significant impact which is postulated in the literature is that of the financial impact of the PV array on the farmer and the farming business. The financial impact is defined by the level of ROI or rent the farmer is receiving. With almost half of all PV array owning farmers estimating their current ROI as 10% or more, this research has shown that farmers perceive that financially they are benefiting substantially from their arrays. One farmer even claimed they were getting a ROI of 25%. Whether farmers are actually attaining this ROI is difficult to tell without conducting detailed case studies. This research also provided some initial data on rent values for PV arrays, which ranged from £850 per acre per year up to £1800 per acre per year, a great disparity for such a small sample (n=39) with no obvious cause.

Perhaps the most interesting data on finance collected in this research was the minimum ROI threshold required for farmers to consider PV arrays, which on average was 9%. This is a relatively high threshold, showing that farmers are demanding in their financial expectations. This demand also increased with increasing farm size, supporting the findings of Blackstock *et al.* (2010) that larger farms are more concerned with profit than smaller ones.

Another aspect of financial gain is the saving on farm electricity bills from using electricity directly from the PV array. Almost half of applicable farmers claimed their bills had been reduced by between a quarter and a half. However 44% of farmers did not know how much they were saving, and as this forms a major part of any ROI calculation, many farmers may be underestimating their ROI. This may explain the slight discrepancy between the quantitative and qualitative data, with the farmer segmentation model showing little positive financial impact but the qualitative data shows evidence of impacts such as increased business stability and investment, improved financial planning and entrepreneurship (see 6.4.1). Using renewable energy as a 'farm subsidy' was also found by Sutherland *et al.* (2012) when analysing the impacts of wind arrays on farms in Aberdeenshire. A further consideration is the impact of PV arrays on the local community. This research shows evidence of interest in arrays from neighbouring farmers (section 5.4). This can be an effective way of encouraging uptake of new technology as farmer's highly value other farmer's experiences. Interaction with local media appears to have varied according to the size of the PV array (section 5.4): larger arrays have a stricter planning process and therefore these farmers have been more engaged with their local communities. However there was only one reported case of tangible benefits for the community, in this case educational visits from schools. Also not all impacts are positive: some of the qualitative data suggests there has been conflict with locals in the planning process (section 6.4.3). Cluster 1 farmers are more likely to consider involvement with community-owned renewables in the future (section 5.4), perhaps due to greater community engagement with their own array. The government is keen to bolster community-owned PV arrays (by introducing a new FiT rate and doubling the size allowed from 5 to 10 MW), and farmers could play a key role in the siting of these arrays (DECC, 2014b). Targeting farmers with existing large arrays may be the most effective way to find traction for these kinds of projects.

The breadth of information on the financial impacts of PV arrays is very valuable as previous research has been with a case study approach, and, due to the commercial sensitivity of some of this data, it also represents the first dataset of its kind. Although anecdotal and not rigorously tested, the evidence from this research indicates that with minimal negative impact on the farm environment and the potential for large biodiversity gains, PV arrays can be beneficial for the farm and local environment if managed correctly. Financial impacts also appear to be largely positive, with many respondents crediting their PV with direct and tangible benefits to the business and their own personal financial planning. However community benefits appear to be under-exploited and much more work is needed to encourage farmers to engage in this area.

7.7 Behaviour

There has been much recent interest in the way government policies interact with, and influence, public behaviour: in particular which policies bring about the most effective behaviour change and outcomes. For example the coalition government set up the Behavioural Insights Team in 2010 in order to explore how this approach could be used across government policy. It was with this in mind that the objectives for this research sought to determine if installing a PV array had implications for wider farmer behaviour. For example, do the environmental and energy issues associated with renewable energy translate into changes beyond installation of a PV array at the farm scale? The qualitative data provided evidence for the prevalence of changes in energy efficiency and carbon footprint behaviour amongst the survey respondents, as well as attitudes towards further renewable arrays.

One of the rationales behind introducing FiTs in 2010 and subsidising small-scale renewable arrays was that it would help to foster behavioural change in the form of increased awareness of energy issues and therefore increased energy efficiency (Ofgem, 2009). This justification has not yet been explored, therefore this research provides some initial evidence. It was found that the issue was not as straightforward as to whether farmers are being more energy efficient post-array installation or not, there was evidence of a much more diverse set of behaviours. 9% of farmers detailed that they were changing their behaviour to use more energy-demanding appliances when the PV array was generating. This was done in order to ensure they are using the cheaper electricity from the array rather than drawing electricity from the grid at a higher price. Those farmers who reported this kind of behaviour owned their arrays, which were less than 0.09MW in size. This is probably because smaller arrays generally do not have an export meter (as it costs extra to install), therefore exports are based on a conservative estimation and paid accordingly. Similar patterns have been found with domestic PV arrays, whereby those with PV show a greater understanding of how their household consumes electricity. Despite this, householders show a preference for exporting the electricity rather than using it themselves in the belief it will benefit them financially, whereas farmers appear to understand the benefits of using the PV generated electricity better (Solar Power Portal, 2014).

Only 11% of farmers declared that they had increased their energy efficiency as a direct result of the process of installing their PV array. One farmer reported already being energy efficient, and three reported changes in behaviour but due to increasing electricity prices rather than their PV array. One respondent even reported being less energy efficient (section 6.5.1). Overall 60% of farmers felt installing a PV array had not affected their energy efficiency behaviour. This supports the initial opinion of Ofgem (2009) who did not think that the FiT scheme would deliver value for money in reducing carbon emissions through energy efficiency, unless further measures such as smart meters or energy efficiency surveys were compulsory alongside FiTs. Therefore emphasis should be placed on other policy mechanisms for achieving energy efficiency, as both large-scale and small-scale renewable generation does not appear to contribute to this goal.

Another area of behaviour which was explored in this research was whether farmers had reduced their wider carbon footprint as a result of having a PV array. For example this may involve reducing fuel usage or changing ruminant diets to produce less methane. Although 14% of farmers reported having reduced their carbon footprint, it appears to be as part of an on-going plan to become more sustainable that pre-dates the installation of the PV array. One farmer cited carbon footprinting reduction as a by-product of reducing costs through more efficient resource use. Two farmers feel their PV array has made them more aware of carbon footprints but haven't actually acted on this (section 6.5.2). Overall an overwhelming majority, 86%, have not actively reduced their carbon footprint since installing a PV array. This evidence indicates that in order to have wider farm benefits, and in order to help the farming industry meet their emissions targets, further engagement is needed to extrapolate the low carbon benefits of PV into other areas on the farm.

A further area of interest was identified in the literature. Surveys by CCgroup (2013) and Frazer (2013) found that farmers who already had renewables were very likely to install further arrays. However this research has showed that respondents are generally negative about installing further renewable technologies on their farms. The average response was that they would be unlikely to install renewables over the next 5 years (section 5.2.3). What was interesting though, was that 10% of farmers did already have another PV array on their farm, and 31% had another renewable technology. This shows evidence of repeat behaviour. For those who only have one array, the negativity towards installing further renewables is perhaps because the arrays are only a few years old and they are waiting to see how their ROI changes over time.

The vast majority of farmers expressed little change in their behaviour in relation to energy efficiency behaviour and reducing their carbon footprint. However one group of farmers (9%) were thinking more about the way in which they use their electricity in order to maximise the benefits from the PV array, re-organising farm duties in order to do electricity demanding jobs during the day. Installing a PV array did appear to have an effect on attitude though, as on average farmers were negative about installing further renewables, despite many of them having more than one renewable technology or array. It therefore seems that the process may have affected farmer attitudes, but not enough to directly influence behaviour.

7.8 Summary

This chapter has discussed some of the main findings from the quantitative and qualitative data in relation to the project objectives, analysing them alongside the literature and in light of government renewable energy policy. Many of the findings presented here are the first of their kind in relation to renewable energy and PV, and will add to the small evidence base surrounding renewable energy uptake in the UK. Although the findings on PV array impacts and subsequent behaviour do not apply directly to the conceptual model, the findings on drivers and barriers add detail to the framework presented in the model.

Overall the respondents engaged well with the research; however limitations with the sampling database resulted in a restriction on the number of surveys which could be sent out. Another limitation in the interpretation of the data is the farmer segmentation model, as missing data prevented the use of some of the respondents in the factor and cluster analysis. The model shows the presence of two defined clusters, and can be used in order to tailor PV communication and policy towards different groups in order to be most effective.

The data confirms the presence of two separate drivers for PV installation as identified in the literature: environmental and financial, although some farmers are driven by a mixture of the two. This can be affected by farm size, as larger farms are more demanding of the ROI they require to undertake PV projects. It was also shown that those with higher education levels are more likely to install a PV array, perhaps because they have more confidence in undertaking large-scale projects or a more positive attitude towards renewables in general. Understanding the extent of financial drivers amongst farmers is important, in light of the imminent cuts to the FiT scheme and whether this will deter farmers from installing further PV arrays.

Some of the barriers to PV installation which were identified in the literature were not raised as a significant issue in this research, such as choosing a PV supplier, connecting to the grid and uncertainty over renewable energy policies. Access to finance was also not a problem for many, although it was more difficult for tenant farmers. The research also showed a lack of engagement with the local community, which can be problematic for planning permission, a barrier which was particularly challenging for large-scale ground arrays.

Due to the rapid increase in installations since 2010, there is little evidence for the impacts of ground-mounted PV arrays on the environment, but this research indicates that the impacts are positive. This includes more extensive use of land and increases in biodiversity, but only if managed correctly. The financial impact on farmers also seems to be positive with many getting very good ROI or rental prices. However this study has shown that many farmers are unaware of the impact of the array on their electricity bills, and therefore may not be calculating their ROI correctly. The research also showed little engagement with local communities and therefore little impact, resulting in wasted opportunities for a wider social benefit (in the form of direct investment, discounted electricity, increased green space for example). Many farmers do express a desire for involvement with community-based renewable schemes, and at a time when the government want to encourage more of these kind of schemes, farmers may be a good target audience for changes to FiT policy.

This research also shows that farmers are neither more energy efficient or that they have reduced their wider farm carbon footprint since having their PV array installed. As the former was one of the justifications for subsidising small-scale renewable energy arrays through the FiT scheme, this is an important finding. A proportion of farmers do understand the benefits of PV generated electricity well though. Further engagement is also needed to encourage farmers to continue reducing their carbon footprint through other on-farm measures. This research also shows that many farmers already have other renewable arrays, but overall are negative towards installing any more.

There was a notable absence of any mention of climate change in the qualitative data, showing that farmers may not be making the link between climate change, carbon and renewable energy.The final chapter will provide some conclusions for this research, outline the impact on policy and suggest areas of further work.

Chapter 8. Conclusion

8.1 Introduction

This final chapter will summarise the work presented in this thesis, highlighting the key findings from the quantitative and qualitative data collected. It will then go on to explore the implications these have for government policy, before exploring some of the limitations of this research which must be kept in mind. The chapter will finish with suggestions of areas for future research, before some final concluding remarks.

8.2 Key Findings

The aim of this study was to explore the role that PV is playing in British agriculture, in order to provide an initial analysis of the recent expansion of PV arrays. The literature was analysed in order to develop the following research questions:

1. Are there any common characteristics of the farms with PV arrays and the farmers/landowners which install them?

   The farms sampled in the survey were more likely to be located in the South West region of England and less likely to be located in the North of the country. This is because of higher levels of irradiation in the South West (although this pattern may soon change with the grid almost at capacity in some places). The farms are also more likely to be poultry farms and less likely to be arable farms, as poultry farms require large amounts of electricity to maintain highly controlled environments, and also have large barn roofs available for panels, whereas arable farms are often situated on high grade land where planning permission for non-agricultural use would be difficult to obtain. There are also fewer very small/small farms and more medium/large/very large farms in the sample, presumably due to greater electricity usage and financial capital. The farms in the sample were also more likely to be owned than would be expected, again probably due to greater security of tenure and access to finance. There was a highly significant difference in education levels, with the respondents being more highly educated than would be expected, initial data suggests they are more confident at taking on large-scale projects, or may have a more positive attitude towards renewables in general.

2. What are the motivations behind farmers installing PV arrays, and have their farming decisions altered since installation?

This thesis has shown throughout the presence of two main drivers of PV installation: financial and environmental ones. Those who are environmentally driven tend to have smaller PV arrays. For some it is a business opportunity, and larger farms tend to be more demanding in the level of financial gain needed for investment. These drivers are not mutually exclusive though. Understanding these drivers is important as farmers with different motivations will respond differently to any policy changes.

This thesis also aimed to explore whether the process of installing a PV array altered farmers' behaviour. One of the rationales behind introducing renewable energy subsides was that it would help to increase energy efficiency (Ofgem, 2009). The evidence showed a range of behaviours, with 14% of farmers becoming more energy efficient and the majority reporting no change in behaviour. Interestingly 9% of farmers switched to using more energy-demanding appliances during daylight hours, showing a good understanding of how to maximise the benefits of PV generated electricity for their businesses, one which does not appear to be present in a domestic setting (Solar Power Portal, 2013).

Whether farmers had reduced their wider carbon footprint as a result of having a PV array was also explored. Although 14% of farmers reported having reduced it, it was because of an on-going plan to become more sustainable or because of rising energy costs, and not directly due to the PV array. Two farmers felt they were more aware of their carbon footprint but had not tried to reduce it. One other area of farmer behaviour explored was whether the respondents were influenced by their PV array to install further renewables in the next 5 years. Overall opinions about this were fairly negative, although almost a third of farmers did already have another renewable technology.

3. What impacts do solar panels have on the farm environment and farm business?

Just over two-thirds of farmers in the sample have a ground-mounted array, which alter the farm environment more than roof-mounted panels. If the land was arable beforehand, then maintaining grassland may reduce resource use and improve soil condition. 9% of farmers are actively managing the land, using wildflower mixes and landscaping, to improve wildlife habitats and increase biodiversity. Therefore anecdotal evidence suggests that ground-mounted PV arrays can have a positive impact on the farm environment, especially if managed correctly.

Financial impacts on the farm business are also positive, with almost half of farmers estimating their current ROI as 10% or more, and some farmers receiving £1800 per acre per year for their land. Almost half of applicable farmers reported their electricity bills had been reduced by between a quarter and a half, however just under half did not know how much they were saving on their electricity bills. This suggests many farmers could be underestimating their ROI. Other reported impacts include increased business stability and investment, improved financial planning and subsequent entrepreneurship.

4. What are the barriers to more farmers/landowners installing PV and how can these be overcome?

The experiences of these farmers can provide an insight into the barriers faced by other farmers who want to install PV. Some of the barriers which were explored were not identified as issues by farmers on the whole, such as choosing a PV supplier, connecting to the grid and community conflict. Others were identified as a problem by particular groups of farmers: access to finance, planning permission and uncertainty over renewable energy policies were problems for cluster 1 farmers, who had larger capacity arrays. Access to finance is also most likely the cause for a significantly low number of tenant farmers in the sample (1% tenant farmers and a further 16.5% with mixed tenure).

8.3 Implications for Policy

It has been shown that policies that are targeted at certain sub-groups are often more effective, as they take account of differences in attitudes and motivations (Garforth and Rehman, 2006). This section will outline some of the implications for policy that the research has discovered in each of the research themes.

8.3.1 Drivers

The data showed that farmers who were more influenced by financial drivers had larger capacity PV arrays, whereas those who were more environmentally driven had smaller arrays. Currently the government is proposing to change the FiTs to reduce the reliability of subsidies for arrays over 5MW in size through the contracts for difference auctions (see DECC, 2014a for more information). If the financial incentive is reduced, this research suggests that this would encourage smaller capacity arrays. This would make the policy effective as this is what the government wants to encourage, due to the unexpected popularity of large ground-mounted arrays.

Overall the quantitative and qualitative data collected in this research supports the initial findings from the literature review, that drivers for farmers to install PV arrays are usually financial as suggested by Sutherland *et al.* (2012) or environmental, or a mix of both in some cases (Wilson and Hart, 2000). This is important as different farmer motivations will affect their response to any policy changes. For example in May 2014 the government announced another consultation on PV deployment, which proposed removing solar arrays over 5MW in size from the current RO (for which reparations are based on electricity produced), and making them compete with other renewables for a fixed pot of money. It is expected that to encourage smaller scale development, changes will be made to the FiT bands in order to encourage more roof-mounted development (DECC, 2014a). Those farmers that are driven by financial concerns may be put off installing more PV by this reduction in financial support, or may opt for roof arrays rather than field ones, whereas for those concerned about the environment this policy change may not affect their attitudes (and perhaps subsequent behaviour) at all. As this policy change is a specific response to the popularity of large scale field based arrays, predicting farmer’s responses to this change is essential for ensuring the impact is as the government desires.

8.3.2 Barriers

One of the key barriers that policy needs to address in order to encourage more farmers to take up PV is to provide financial support for tenant farmers. Tenant farmers have less capital to secure loans against, and this involves a greater element of risk. Policy needs to encourage a greater diversity of finance options, such as power purchase agreements or lease financing (DECC, 2014b), and also support tenants in negotiations with their landlords.

8.3.3 Impacts

More needs to be done to quantify the impacts of PV arrays on farms, and to ensure that the positive benefits are maximised. This research has shown that many farmers are ignorant of the amount of electricity their array produces, the electricity export price and their current ROI. In order for farmers to be more aware of and manage their PV arrays to full advantage, they need to be provided with training on array performance after it is installed.

In order to maximise the environmental benefits of ground-mounted PV arrays, the land underneath needs to be actively managed to encourage greater biodiversity, ideally through the use of wildflower mixes. Effort must be focused on quantifying the benefits and promoting and encouraging this management further.

A further area of policy that needs to be addressed is the encouragement of community benefits from PV arrays. It is suggested that it is a condition of planning consent that farmers or the developer should make a reasonable effort to engage the local community, for example by information boards near the site or allowing school visits to the site and/or open days.

8.3.4 Behaviour

The government is currently assessing the financial support structure for community-owned PV arrays in order to encourage more of them (DECC, 2014a). This research suggests that the farmers most open to being involved in these kind of schemes are those who already have large ground-mounted arrays. Therefore targeting these farmers would be a good way of securing land for these schemes.

This research has also shown that subsidising PV arrays through the FiT scheme has only had a small impact on encouraging energy efficiency. It would be more beneficial to encourage energy efficiency through other schemes such as the Green Deal.

8.4 Methodological Considerations

The combination of quantitative and qualitative survey data allowed quick and effective data collection, and provided a range of useful data that could be used to triangulate findings. The sample size was limited by the number of farms that could be identified as having a PV array, and therefore the overall number of completed surveys was limited as well. It was enough to provide some insight into this under-studied area, but did provide some limitations for the statistical analysis.

The factor and cluster analysis that make up the farmer segmentation model are subjective processes, and the sample size was at the lower end of acceptable for these tests. The optimal cluster solution was explored using guidance from the literature (Hair *et al.*, 1998) and through looking at the data logically. Using both factor and cluster analysis, and both hierarchical and non-hierarchical techniques, also helped to reduce the subjectivity of this model. This should be borne in mind when making conclusions from the model.

8.5 Areas for Further Research

This research has been one of the first academic studies into the uptake of renewables on British farms, and has identified patterns which require further investigation.

As mentioned in section 7.4, patterns in the age of farmers who have PV arrays could not be identified, so this is a potential source of further research. It would also be worthwhile exploring further the reason why farmers with higher levels of education are more likely to have PV arrays. Education levels may affect attitude towards issues such as climate change and renewable energy, and may also have an impact on farmer self-confidence. It is suggested that policy focuses on farmers with less formal education levels, in order to provide them with the support they need to undertake PV projects.

Further research is also needed on the long-term impacts of PV arrays on the farm scale and across the rural economy. With recent dwindling financial support for both the EU and the CAP budget, and changes to the AES in Britain in 2014, farmers are increasingly looking for reliable income streams. Further work similar to that of Bell and Booth (2010) could be undertaken to establish the impact of the increase in farmer incomes on jobs and local spending patterns. More large-scale work across different sites similar to that of Parker and McQueen (2013) is also needed to establish a robust scientific evidence base for biodiversity changes in solar parks.

One of the most interesting findings related to farmer behaviour that came from this research was farmers switching to using energy-demanding appliances during daylight hours, and the awareness this shows of maximising solar PV benefits. It would be useful to see if this behaviour is replicated with domestic PV arrays or with wind turbines and other forms of renewable energy. It would also be worthwhile exploring why so many farmers were negative about installing further renewables over the next five years.

This research on farmer behaviour has mainly been as a response to the introduction of the FiTs making PV arrays viable. A broader study on the response of farmers to a wide range of interacting issues, such as climate change, energy security and commodity price rises would provide further insight. This research does not provide any information on how estate manager's attitudes and behaviour may be different to those of farmers, an area where very little work has been done (The James Hutton Institute, 2014).

8.6 Final Concluding Remarks

The British farming industry is under ever-increasing pressure to meet their emissions targets and contribute to national GHG reductions, whilst also increasing sustainability and reversing trends in wildlife decline that have been linked to agricultural activities. The installation of ground and roof-mounted PV arrays on farms has increased rapidly over the past four years, and this research sought to provide an initial analysis of this trend.

The financial impacts of solar PV arrays on farming businesses are substantial for many, with the increased income essentially subsidising agricultural operations. For ground-mounted arrays, benefits are also evident through the switch to more extensive land use and management of land for biodiversity gains. This kind of mitigation may not be the most effective in terms of GHG emissions, but as it enables greater economic and landscape sustainability it is arguably more beneficial on the whole.

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Appendix 1: Survey Cover Letter

ROYAL AGRICULTURAL UNIVERSITY
CIRENCESTER

Bethany Ledingham
bethany.ledingham@rau.ac.uk
01285 652531 ext 2374
Monday 4th November

Dear Sir/Madam,

I am a postgraduate student at the Royal Agricultural University (formerly the Royal Agricultural College) studying for an MSc by Research. My research project is exploring the uptake and use of solar photovoltaic (PV) arrays in agriculture, looking at the motivations, barriers and impacts of their use. I am conducting this research because very little work has been done on the interaction between farmers/landowners and renewable energy technologies, so your experiences and response to this survey are extremely valuable.

As part of my research I am conducting a survey of farmers/landowners who already have PV arrays installed, and I would appreciate it if you could fill out the attached questionnaire. You have been selected because the renewable energy planning database identifies a PV array on your farm/estate. It is essential that as many people as possible complete this survey so the results of the research are reliable. Your response will be completely **anonymous** and **confidential.** You have the right to withdraw from this survey at any time.

The questionnaire should only take 15 minutes of your time to complete. If you have any problems or questions then please feel free to contact me using the details above. Please return the completed questionnaire using the freepost envelope enclosed **by Monday 2nd December.** Your participation is very much appreciated.

Yours faithfully,

Bethany Ledingham

Appendix 2: Postal Survey

Solar PV Survey

☑

Please tick the relevant box to indicate your chosen answers unless otherwise stated. Feel free to contact me if you have any questions, using the details at the bottom of the page. The results of this survey will be kept anonymous and confidential.

1. What best describes your role?

Farmer (owner-occupier)		Farm manager	
Farmer (tenant)		Estate manager	
Estate/ land owner (non-farming)		Other (please specify)	

2. What is your gender?

Male		Female	

3. What is your age?

25 years or less		51-75 years	
26-50 years		76+ years	

4. What is your highest level of education?

Primary school		Diploma	
Secondary school		Undergraduate degree	
College		Postgraduate degree	

5. How many years have you been working in agriculture and/or have had responsibilities for owning and/or managing land?

10 years or less		26-50 years	
11-25 years		51+ years	

6. In which British county/counties is your farm/estate?

____

7. Which of the following best describes the main land use on your farm/estate?

Mixed		Arable	
Mixed- Dairy		Arable- Potatoes	
Mixed- Poultry		Arable- Horticulture	
Mixed- Pigs		Other (please specify)	

8. What is the approximate size of your farm/estate?

_____________ acres/hectares **(please delete as appropriate)**

9. Which of the following best describes you and your farm/estate?

The farm/estate is owner-occupied		I am the tenant under an AHA tenancy	
I am the landowner/manager and the land is predominantly rented out under AHA/FBT tenancies		I am the tenant under a FBT tenancy	
I am the landowner/manager and the land is predominantly rented out under other (non AHA/FBT) arrangements (please specify)		Other (please specify)	

10. If you are an FBT tenant, what is the approximate length of your tenancy?

______________ Years

Not applicable	

11. Is your farm/estate involved with any of the following schemes or groups?

Organic farming		Conservation grade	
Converting to organic farming		Farming and Wildlife Advisory Group	
Entry level stewardship		Other agri-environment scheme or group (please specify)	
Higher level stewardship		Not applicable	

Please answer these questions if possible, if it is not possible then please move on to the next question. If you have more than one PV array then please provide answers for both.

12. What is the total capacity of the PV array?

______________ KW/MW **(please delete as appropriate)**

Don't know	

13. In the last year, how much electricity was generated by the PV array? Give a value for the last month if the array is less than a year old.

______________ KWh/MWh per month/year **(please delete as appropriate)**

Don't know	

14. What is the approximate size of the area covered by the PV array?

______________ m^2/ hectares/ acres **(please delete as appropriate)**

Don't know	

15. When did the PV array begin producing power?

______________ (DD/MM/YY)

16. What is the location of the PV array?

Ground-mounted		Both	
Roof-mounted			

17. What scheme does the PV array come under?

ROCs (Renewable Obligation Certificates)		Don't know	
Feed-in-Tariffs (FiTs)		Not applicable	

18. Please tick **all that apply** to the PV array.

The PV array is owned by the same person as the farm/estate.		The PV array is **not** owned by the same person as the farm/estate, but the farm/estate owner receives free electricity from it.	
The PV array is **not** owned by the same person as the farm/estate, but the farm/estate owner receives rent for the land or roof space it uses.		The PV array is **not** owned by the same person as the farm/estate, but the farm/estate owner receives ROCs from it.	

The PV array is **not** owned by the same person as the farm/estate, but the farm/estate owner receives a payment linked to the amount of electricity generated.		The PV array is **not** owned by the same person as the farm/estate, but the farm/estate owner receives (FiTs) from it.	
Other (please specify)			

19. In the last 12 months, what percentage of energy generated by the PV array is being exported to the grid?

None		51-75%	
25% or less		76-100%	
26-50%		Please specify if known	%

20. What is the electricity generated by the PV array being used for on your farm/estate? **Please tick all that apply.**

Farm/estate household		Grain storage and drying	
Livestock housing		Horticulture	
Milking facilities		Not applicable	
Other (please specify)			

21. If the PV array is ground-mounted, what was the land used for **before** the array and what else is it used for **now** the array is installed?

	Before	**Now**
Livestock grazing (please specify animal and whether permanent pasture or grass ley in a rotation)		
Grassland without grazing		
Crops (please specify typical rotation)		
Wildflower strips/seed/ nectar mixes		
Cover feed crops for game		
Not applicable		
Other (Please specify)		

22. To what extent do you agree or disagree with the following statements?

	Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**	**Not applicable**
The main aim of my farming/land management is to try and make as much profit as possible.						
My farming/management decisions are based mainly on financial considerations.						

I installed solar PV because I thought it was a good way to diversify my business.						
I installed solar PV because I thought it provided a good return on investment.						
I installed solar PV because I thought it would help reduce the impact of electricity price rises on my business.						
I am concerned about the possible impact of climate change on my business.						
I installed solar PV because I thought it was a good way to reduce my business' carbon footprint.						
Choosing a company to supply and install my PV array was difficult.						
Having the PV array installed was disruptive to my business.						
Securing the finance needed for my PV array was difficult.						
I found the planning process associated with my PV array difficult to negotiate.						
Connecting my PV array to the grid was easy.						
When planning my PV array there was plenty of information available to						

me.						
When planning my PV array I was worried about uncertainty with renewable energy policies.						
When planning my PV array I was worried about local opposition to it.						
I was confident in my ability to have my PV array installed successfully.						
Installing my PV array was a challenge for me.						
Other people's opinions are important to me when I make decisions about my business.						
Other people's opinions influenced me to install my PV array.						
I have had interest from other landowners/farmers since installing my PV array.						
I have had interest from local media since installing my PV array.						
I am interested in being involved with community-owned renewable energy schemes.						
The increased income from my PV array has made the business more financially secure.						

The increased income from my PV array has allowed me to invest in my business.						
I have gained confidence in reducing my business carbon footprint since installing my PV array.						

23. Has the experience of having a PV array made you…?
    a. Change your farming/land management methods to be more environmentally friendly? **(Please explain)**

    b. Become more energy efficient? **(Please explain)**

    c. Reduce your carbon footprint in other ways? (Such as reducing fertiliser use) **(Please explain)**

24. How likely are you to install any of the following renewable energy technologies on your farm/estate over the next 5 years?

	<u>Very Unlikely</u>	<u>Unlikely</u>	<u>Neutral</u>	<u>Likely</u>	<u>Very Likely</u>	<u>Already have</u>
More PV panels						
Anaerobic digester (AD)						
Biomass boiler						
Solar thermal technology						
Wind turbines						
Other (please specify)						

If you would rather not answer any of the questions below then please move on to the next question.

25. What was the approximate price of the PV array?

£25,000 or less		£250,001-£500,000	
£25,001-£50,000		More than £500,000	
£50,001-£100,000		Please specify if known	£
£100,001-£250,000		Don't know	

26. If an external company owns the PV array, how much rent do you receive from them?

£ ____________ week/ month/ year **(please delete as appropriate)**

Not applicable	

27. If you export some of the electricity, what price are you paid for it?

£ ____________

Don't know		Not applicable		KWh

28. What was the **predicted** return on investment (ROI) when you installed the PV array?

1-3%		7-9%	
4-6%		10% or more	
Don't know		Please specify ROI if known	% per year

29. What is the **current** return on investment (ROI) for the PV array?

1-3%		10% or more	
4-6%		Don't know	
7-9%		Please specify ROI if known	% per year

30. What would have been the lowest expected ROI that would have made the project worthwhile for you?

________________ %

31. Please give an estimation of your total farm/estate electricity bills per month **before** and **after** the PV array was installed.

Before £________________ per month

Don't know		Not applicable	

After £________________ per month

32. What is the annual turnover of your business? **This question is voluntary.**

£25,000 or less		£250,001-£500,000	
£25,001-£50,000		More than £500,000	
£50,001-£100,000		Please specify if known	£
£100,001-£250,000		Don’t know	

33. Are there any other comments that you wish to add about your experience with PV, particularly why you choose to install it, what problems you faced and what impact it has had on you and your farm/estate?

Thank you again for taking the time to complete this questionnaire. If you know of any other farmers/landowners who also have a PV array, it would be very much appreciated if you could provide their contact details, or even just the name and location of the farm/estate. You will not be identified as the source of this information, and these details will only be used for the purpose of this questionnaire.

In addition to this questionnaire, my research also involves calculating the carbon footprints of some case study farms which have PV arrays, in order to calculate the impact it is having on their total carbon footprint. This would involve a telephone call to collect data about your farm, such as fertiliser and fuel use, and the results of the calculation would be available to you for your own use. If you would like to be a case study farm then please fill out your name, telephone number, email address (if applicable) and the hours during which you would like to be called in the box below. **This page will be removed from the survey on receipt, in order to keep your answers anonymous.**

Please return this questionnaire using the freepost envelope provided by Monday 2nd December.

Thank you very much for your time.

Appendix 3: Factor Analysis Methodology

There is little agreement in the literature on a precise sample size which is adequate for factor analysis (Pallant, 2010) however as with most statistical tests the larger the sample the more reliable the results. Some people argue that it is not the absolute sample size that is important, but the ratio of subjects to items. There should be at least five cases for each variable, so 125 cases for a 25 variable dataset. However 50 can be treated as an absolute minimum, with at least 100 desirable (Hair *et al.* 1998). This dataset consisted of only 92 cases but it was decided to see if the other tests for suitability failed before ruling out factor analysis.

Before factor analysis was undertaken, it was important to check the data for outliers. The Mahalanobis D^2 method was used to check for outliers, but no variables had a p value of below 0.001 which is required for rejection, and therefore no outliers were identified and no variables removed (Hair *et al.*. 1998)

The next step was to explore the level of multicollinearity between variables, this is essential as the aim of factor analysis is to identify sets of variables based on their correlation. A correlation analysis of the variables was undertaken, and the results analysed. Correlation needs to be greater than +-0.3 (Beaumont, 2012), which all variables satisfied so none were removed. Excess multicollineraity of 0.9 or more was also checked for, to identify variables which are too similar, but there were none. There all 25 variables were included in the analysis.

Further tests were used to check for factorability. The Bartlett Test for Spherity ensures that a sufficient number of correlations are statistically significant (Pallant, 2010). The test gave a chi-square value of 447.390 and a p value of 0.000, thus justifying the use of factor analysis.

The Kaiser-Meyer-Olkin measure of sampling adequacy ranges from 0 to 1, with values over 0.5 suitable for factor analysis (Hinton, 2004). The value for this sample was 0.559, which is just acceptable. Therefore it was decided to proceed with the analysis.

In order to extract the correct number of factors from the exploratory factor analysis, three criteria were used. The first was the eigenvalue rule, where the eigenvalue of a factor represents the total variance explained by that factor, and a number higher than 1 is significant. Nine factors met this criterion. The second criterion was analysing the scree plot, which plots eigenvalues against the number of factors. The point at which the curve begins to change shape and flatten provides an indication of the number of factors. This showed seven factors should be retained. The third criterion is the calculation of cumulative percentage of total variance explained by the extracted factors. At least 60% should be explained by the extracted factors (Hair*, et al.* 1998). Nine factors explain 72.759% and 7 factors explain 61.530%, therefore seven factors were chosen as the final factor solution.

Confirmatory factor analysis was run with a seven factor solution, and a factor rotation method was chosen. Factor rotation does not change the underlying solution but presents the pattern of factor loadings in a way which is easier to interpret. There is no rule to choosing the type of rotation, however orthogonal approaches (where the factors are extracted so that their axes are maintained at 90 degrees- each factor is independent of all other factors (Hair, 1998) are easier to interpret than oblique ones (where the extracted factors are correlated (Hair, 1998; Pallant, 2010). The most common is Varimax with Kaiser normalization, as it is easier to interpret, therefore this was chosen. (Acton and Miller, 2009) state that usually the choice of rotation will not majorly affect the outcome or interpretation of the factor analysis.

Appendix 4: Cluster Analysis Methodology

During the factor analysis, a factor score for each factor was given to each respondent. These were then used as variables for the cluster analysis. The similarity measure that was to be used had to be chosen carefully, as this effects the way in which the clusters are compared to each other and subsequently grouped. The Squared Euclidean distance measure is the most commonly used. It represents distances that can be measured with a ruler, and is the most straightforward distance measure. Ward‘s method is the most commonly used clustering algorithm, it is an analysis of variance approach to evaluate the distances between clusters. After careful consideration and advice from the literature, these two methods were selected for the clustering process (Burns, 2009).

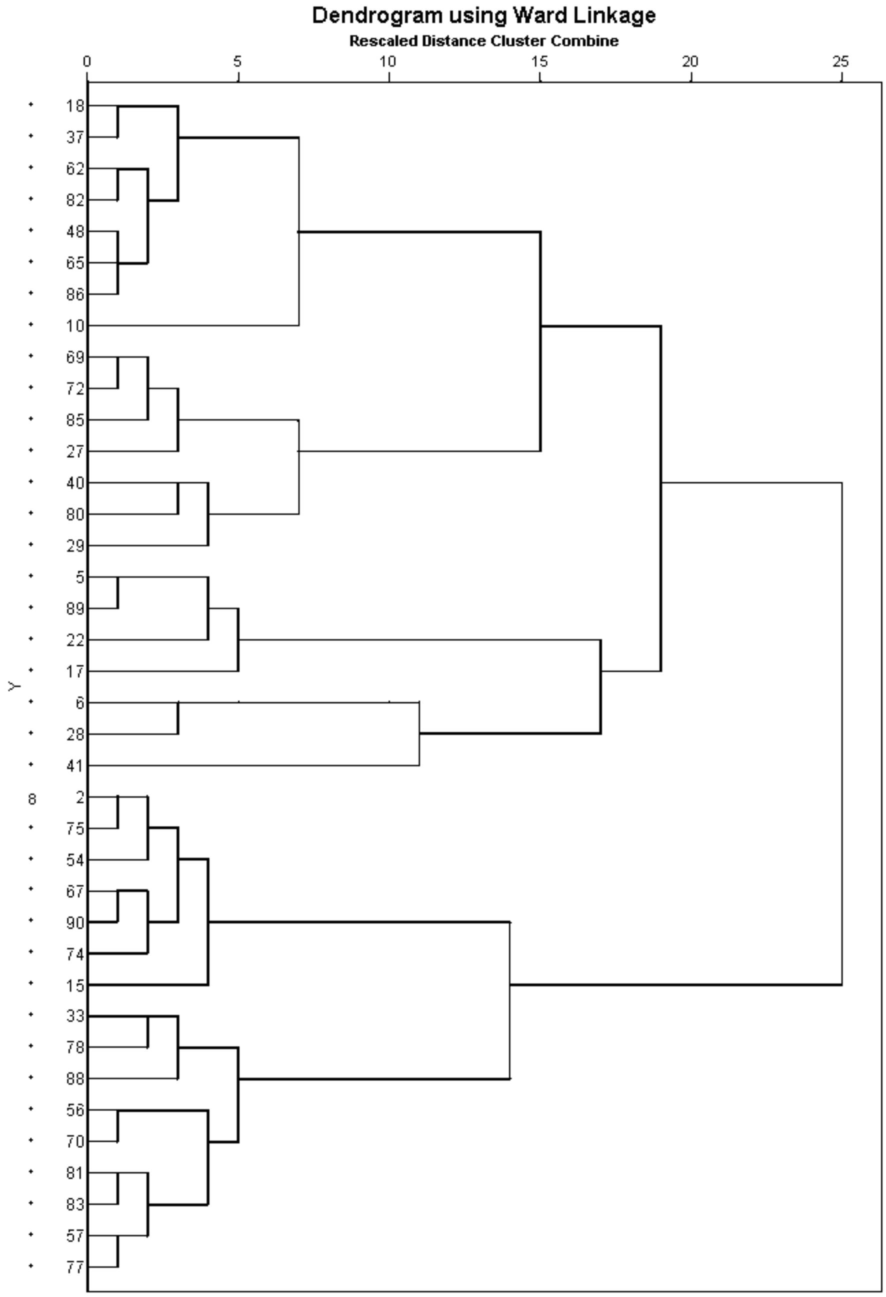
Agglomerative hierarchical cluster analysis was chosen, followed by non-hierarchical cluster analysis. The former explores the data and allows the researcher to identify the optimum number of clusters, whilst the latter assigns cases into a predetermined number of clusters. Using them in combination reduces the effect of the disadvantages of each method (Burns, 2009).

The hierarchical analysis (n=38) produced cluster coefficients and a dendrogram plot, both of which were used to identify the optimum number of clusters. The partition process was confined to between two and ten clusters, in order to establish a manageable number of clusters. The increases of the cluster coefficients were examined (see Table 6-1). Small changes in the increases show that very similar clusters are being merged, so these were calculated for 12 clusters in order to examine the differences between the clusters being merged at each stage.

Number of Clusters	Agglomeration Coefficient Previous Step	Agglomeration Coefficient This Step	Agglomeration Coefficient Change
2	266.678	227.77	38.908
3	227.77	198.222	29.548
4	198.222	172.613	25.609
5	172.613	149.472	23.141
6	149.472	128.797	20.675
7	128.797	111.605	17.192
8	111.605	101.211	10.394
9	101.211	91.212	9.999
10	91.212	83.097	8.115
11	83.097	75.702	7.395
12	75.702	69.64	6.062

Agglomeration schedule for factor analysis.

The largest change is between clusters 2 and 3, with a smaller but further significant change between clusters 7 and 8. The dendrogram was also analysed (see Figure 6-1), and it showed the presence of two defined clusters, but did not support the presence of seven defined clusters. Therefore a two cluster solution as determined as the most suitable.



Dendrogram output from SPSS for factor analysis.

The second step in the cluster analysis was to run non-hierarchical k-means cluster analysis, using a two cluster solution as suggested by the hierarchical analysis. As before, the factor scores from the factor analysis were used as the clustering variables. The cluster centres for each factor were given in the output, where a positive value shows a higher than average importance of that factor and vice versa.